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Welfare and environmental effects of short-haul flights bans

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ABSTRACT

This paper explores the efficacy of short-haul flights bans in reducing environmental external costs and its effects on welfare. Recently implemented by several European countries, the ban policy assumes that the air traffic lost will be diverted to rail giving environmental gains. A model where users are also allowed to use private car and account for all transport external costs is proposed to check this measure. The ban will provoke a shift in the modal split and affect total traffic levels. Rail prices will rise, users surplus and net welfare will fall. External costs are not necessarily reduced. Finally, an ex-ante assessment is done finding that environmental costs only decrease in the Madrid-Barcelona corridor, increasing in the Madrid-Valencia one. Social welfare net of all external costs decreases by 19.6% and 3.1% respectively. Thus, a case-by-case approach for implementing short-haul flights bans would be advisable.

1. Introduction

With the purpose of reducing greenhouse gas (GHG) emissions and respond to climate change challenges, several European countries (Austria, France, The Netherlands) are recently implementing short-haul flights bans on Origin-Destination (OD) routes when there is a rail alternative. Although the aviation industry and organizations such as International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO) are very concerned and are devoting their efforts to limit the climate impact of travel, bans are not welcomed. One of the rationales of the ban policy is that it will provoke a shift in the transport modal split in favor of a more environmentally friendly mode such as rail and, in particular, the high-speed rail (HSR). However, a proportion of users may react to the short-haul flights ban by increasing the number of trips by private cars, which is a transport mode alternative that generates higher external costs than air transport. According to the US Environmental Protection Agency, rail supposed 2.1% in the breakdown of transportation-related GHG emission in the United States in 2019. Commercial Aircraft accounted for 7.3%, while cars plus light duty vehicles reached 58.9%, that is, eight times more [27]. Therefore, before adopting a ban policy in a given OD transport market, it is important to carefully assess their effects on the overall account of external costs and also the welfare consequences generated on users due to the reduction in competition.[1]

Air traffic has exponentially grown in the last two decades, 86% between 2000 and 2019 [16]. This tendency accelerates the increasing environmental pressure of transport activity (28.5% of global GHG emissions in the EU-27). Within the transport sector, civil aviation is responsible for 13.4% of GHG emissions (148 Mt CO2 equivalent) while rail accounts for 4% of GHG emissions (4.1 Mt CO2 equivalent) [16]. Besides CO2 emissions, aviation emits other air pollutants, which are estimated to represent half of the climate warming effects [7]. Considering the overall environmental costs in monetary terms, external costs of short-haul flights is estimated at 4.3 €-cent/pkm. The high environmental costs have positioned aviation in the spotlight of the climate change debate. Public authorities and organizations are bringing to the table new policy instruments that reduce air transport activity towards more environmentally friendly modes like HSR, the external costs of which are three times lower than short-haul flights (1.3€-cent/pkm), see [15]. For instance, pricing policies, technology standards, infrastructure measures, or banning domestic short hauls. Proposals to substitute shorter flights by rail were expressed in the 2011 European Commission's White Paper (Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system). To

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[1] [9] also consider the effect of external costs in the analysis of optimal pricing in interurban passenger routes.

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illustrate, the flight route between Vienna-Salzburg, the Amsterdam-Brussels and Paris Orly-Lyon routes are examples of such ban policy. This scheme was also considered by the Spanish Government who recommended banning short-haul flights in the following years [28] and has been discussed in Germany, Italy and the UK (see [14]).

Our objective is to evaluate the effects of banning short-haul flights (a no-flights policy) when transport services are performed on routes where mode substitution is possible. We consider OD routes where trips can be made by air, HSR and road (users have the option to use their private car). The assessment of the proposed market-based measure involves not only looking at its effects on user surplus and company profits, but also on the level of external costs, including environmental damages, derived from the shift in the modal split.

The paper is structured into two parts. In the first part a formal model is used to obtain the equilibrium corresponding to two different scenarios. Firstly, the benchmark scenario characterizes the equilibrium when the three modes of transport are available to passengers. An HSR operator and an airline compete by setting prices. The equilibrium prices determine the modal split of passengers for train, air and road transport that allows us to calculate user surplus, firms profits and external costs. The latter are obtained as a weighted sum of passengers, where the weights are the per unit external costs per mode of transport. Secondly, the short-haul flights ban scenario corresponds to the case where only the HSR operator sets the equilibrium price. As in the former scenario, a modal split for passengers is obtained that allows us to find conditions for the short-haul flights ban (the no-flights policy) to be detrimental for society. In the second part, we provide an empirical application that consists of a calibration of the model for the two most important OD markets in Spain: the Madrid-Barcelona and the Madrid-Valencia corridors.

Our results show that when the per unit external cost of road transport is sufficiently large, the implementation of a no-flights policy turns out to be detrimental to society as it generates larger external costs. Considering that the per unit external cost of air transport is larger than that of HSR services, the condition on the external cost of road transport becomes weaker the larger the preference of users for the rail upon the air transport, as well as the better substitutes transport modes are for the symmetric case. Finally, we find that the no-flights policy increases HSR service price which leads to an increase in HSR profits, but to a decrease in user surplus and total profits for the symmetric case, leading to a welfare decrease.

The model is calibrated for the two largest corridors in Spain in terms of total traffic: Madrid-Barcelona and Madrid-Valencia. The former is dominated by the HSR mode, while the latter by private car use. Then we may simulate the effects of a short-haul flights ban in these corridors. The simulations confirm the results put forward in the theoretical analysis, that is, an increase in HSR prices that implies increases in HSR profits and user losses; a fall in welfare and an increase in external costs (damages) follow in a no-flights setting. Our empirical analysis shows that welfare gross of external costs may slightly decrease (by 1.1%) in the Valencia-Madrid corridor or notably decrease (by 14.8%) in the Madrid-Barcelona corridor. From a transportation viewpoint it is relevant to distinguish between all external costs and those associated with the environment. Regarding the latter, we find that they may be smaller (10.9%) when removing air transport in the corridor where it carries quite air traffic. However, total external costs always increase, the size of which is in the range of 1.9–13.2%. We also find that users suffer a loss of between 0.7% and 19.7%. Altogether, social welfare net of all external costs is lower under the no-flights policy - the impact is stronger in the Madrid-Barcelona corridor (19.6%) than in the Madrid-Valencia corridor (3.1%). Finally, it is remarkable to note that the ban would induce an increase in environmental external costs of 12.2% in the Madrid-Valencia corridor.

We also discuss what happens when the degree of product differentiation between modes and the cost of private car use change. The above noted results remain qualitatively valid. A final robustness check is carried out considering competition in HSR services. The size of the negative effects that arise under no HSR competition are lessened. The paper is organized as follows. Section 2 includes the literature review. Section 3 presents the model. Different subsections describe equilibria of two scenarios; the benchmark scenario where HSR and airlines compete for passengers (subs. 3.1), as well as the short-haul flights ban scenario (subs. 3.2). Subsection 3.3 offers the effects of the no-flights policy. The empirical application is given in Section 4. Finally, we conclude with some remarks and policy recommendations in Section 5.

2. Related literature

To reduce emissions and limit climate change in aviation, much of the literature has studied proposals ranging from taxes to emission reduction schemes and changes in travel behaviour. Thus, [19] discuss the perceived necessity of flights and implications for a cleaner aviation system. For Switzerland, [38] survey the effects of market-based measures and other governmental policies to reduce CO2 emissions. They conclude that flight tax programs are weakly effective, and may even generate additional transport traffic. Using synthetic control methods, [23] provide an ex-post evaluation showing that the policy change in the EU Emission Trading System will reduce flight frequency, increase load factors and significantly impact low-cost and regional carriers and short-haul routes. A review of papers on the transition policies and challenges for mitigating the climate impact of aviation can be found in [18] and [24]. While the effectiveness of a variety of voluntary, market-based and regulatory measures is carefully scrutinized, to the best of our knowledge, ours is the first formal study on the welfare and environmental effects of a short-haul flight ban measure (market-based), which, as mentioned in the introduction, is currently in the policy arena.

A more general view concerning CO2 reduction measures is required and should look at modal interactions - see [40] for a survey on recent research on air-HSR competition and [22] for a survey on the environmental implications of the interplay between HSR, air and road transport. The development of HSR networks that is taking place around the world is aimed at improving connectivity and stimulating regional economic growth. More importantly, a major policy objective of the HSR technology is the reduction of the negative environmental impact of transportation. The entry of HSR negatively affects air traffic, fares and flight frequencies. However, as noted by [17], the introduction of HSR may generate new travel demand, which brings benefits to users, yet it is not straightforward to conclude that HSR projects have positive environmental effects unless a broad consideration of all transportation modes is undertaken. The formal contribution by [11] illustrates the tradeoff between the substitution and the traffic generation effects. The introduction of HSR in a setting where operators compete in quantities may be detrimental for the environment as compared with monopoly. [12] consider a more general model and confirm through numerical analysis that competition has negative environmental consequences when the ratio between HSR and air transport emissions is sufficiently large. The recent contribution by [10] offers an ex-post assessment of net CO2 emissions that accounts for the aforementioned demand effects in long distance HSR for the Beijing-Shanghai corridor; when HSR attracts substantial traffic from highway and aviation sectors, net emissions reductions can be realized.

There is also a complementarity between air transport and HSR that should not be disregarded. On this respect, collaboration between airlines and HSR may be environmentally beneficial since HSR travel is certainly attractive for trips in the range of 300–700 km and less polluting than air travel - see [34]. There are a few analytical contributions that study the impact of HSR-air cooperation and show that it is beneficial for connecting passengers and detrimental for those in the HSR accessible market [33,21,39]. Under quantity competition, [5] explore the advantages of airline-HSR partnerships for total traffic and welfare. Under price competition, [2] study the scope of inter-modal cooperation in a transport network noting that welfare gains can be significant. In a transport network, the paper by [20] theoretically studies an integrated policy consisting of taxing air transport while subsidizing the railway in order to establish conditions under which air traffic is reduced. We shall consider an OD market, as in [11,12], assume price competition and contemplate the private car option. In contrast, it is not the introduction of HSR (the less pollutant mode) but the elimination of air services (the most pollutant mode) whose welfare and environmental consequences are examined.

Only some recent contributions explicitly investigate the effects of policies that ban short-haul flights from an applied perspective. For the case of intra-European flights and HSR, [6] analyze route substitutability finding that banning domestic short-to-medium haul flights, where alternative connections are feasible, is positive in terms of CO2 savings, yet the benefits are not equally distributed across Europe. In contrast, [14] argue that a ban policy should consider absolute emissions and not just look at the substitution effects towards a more efficient travel mode. These authors conclude that short-haul flights bans have limited effects on emissions reduction as the share of fuel burnt in such type of flights is barely 5.9% of the total despite they account for 27.9% of departures in 31 European countries. Finally, [30] offer a quantitative analysis of the effects that would follow from substitution of short-haul flights with rail services for a number of travel corridors in Germany. Their estimates point at significant reductions in CO2 emissions - between 2.7% and 22%. We complement this line of research by providing a formal setting that accounts for modal interactions between air, HSR and private car transport to conveniently consider all demand effects. An empirical application to two Spanish corridors allows for an informed assessment of the impacts of a short-haul flights ban on external costs, user surplus and social welfare.

3. The model and analysis of equilibria

Consider an OD market connecting two cities where a high-speed-rail (HSR) operator is competing with an airline and users have the option to use their private car. Thus, three differentiated transport modes are competing for passengers. Considering another mode increases computational complexity without adding any further insights into the analysis. In order to model demand, we define the following Spence-Dixit representative user utility function (see [13]):

$$U(q_t,q_a,q_c) = y + \sum_{i=t,a,c}\alpha_i q_i - \frac{1}{2}\sum_{i=a,t,c}\beta_i q_i^2 - \gamma(q_tq_a + q_tq_c + q_aq_c) \tag{1}$$

The representative user's budget constraint is defined by $I = p_tq_t + p_aq_a + r_cq_c + y$; where subscript t stands for rail transport, a for air transport and c for car, q_i denotes the number of trips and α_i the maximum willingness to pay for travelling by mode i, for $i = t, a, c$. Maximum willingness to pay per mode encompasses a number of characteristics for each transport mode such as service quality, travel time, frequency of services, reliability, likelihood of congestion and so on that are considered by users to make their decisions.[2] Differences in α's owe to differences in such characteristics. For instance, focusing on travel time it usually includes in-vehicle time, plus access/egress time and finally the mismatch between user's preferred departure time and the actual time of departure. Thus, an air journey has lower in-vehicle time than a car or train journey, but suffers from longer access/egress times in addition to schedule delay costs. It may be possible that a car journey has longer in-vehicle time than an air journey, but lower total travel time since it does not incur in other items. Similarly, p_t and p_a are the HSR and airline prices, while r_c is the cost of private car use (fuel, depreciation, maintenance and repair, etc.), I is the user's income and y stands for the numeraire of the economy. Services become less differentiated as γ tends to β's. In fact, the ratio $\frac{\gamma^2}{\beta_i\beta_j}$ expresses the degree of product differentiation between modes i and j ranging from zero for independent goods to one for perfect substitutes (see [36] page 146). Then, less differentiation implies ratios closer to one. A system of inverse demand functions is obtained from the maximization of the utility function in (1) subject to the budget constraint as follows:

$$p_t(q_t,q_a,q_c) = \alpha_t - \beta_tq_t - \gamma(q_a + q_c), \tag{2}$$

$$p_a(q_t,q_a,q_c) = \alpha_a - \beta_aq_a - \gamma(q_t + q_c), \tag{3}$$

$$r_c = \alpha_c - \beta_cq_c - \gamma(q_a + q_t). \tag{4}$$

The first two equations above correspond to the inverse demand functions for the HSR and airline transport services, while (4) is the condition that defines the optimal use of private car. Since r_c is parametric but affects the operators' decisions, we solve for q_c in (4), substitute back in (2) and (3) and then solve for p_t and p_a leading to the following inverse demand system:

$$p_t(q_t,q_a) = a_t - b_tq_t - dq_a, \tag{5}$$

$$p_a(q_t,q_a) = a_a - b_aq_a - dq_t. \tag{6}$$

Note that $q_c = \frac{\alpha_c - r_c - \gamma(q_a+q_t)}{\beta_c}$, with $\alpha_c > r_c$, and $a_k = \alpha_k - \frac{\gamma(\alpha_c - r_c)}{\beta_c}$; $b_k = \frac{\beta_k\beta_c - \gamma^2}{\beta_c}$ for $k = t, a$ and $d = \frac{\gamma(\beta_c - \gamma)}{\beta_c}$.[3] The benchmark scenario features a duopoly situation, where the HSR operator and the airline choose the profit-maximizing prices. Then, a short-haul flights ban is implemented and there is just HSR service. Since we assume that firms compete in prices, the demand system derived from (5)–(6) is:

$$q_t(p_t,p_a) = \frac{b_aa_t - da_a - b_ap_t + dp_a}{b_tb_a - d^2}, \tag{7}$$

$$q_a(p_t,p_a) = \frac{b_ta_a - da_t - b_tp_a + dp_t}{b_tb_a - d^2}. \tag{8}$$

The HSR operator and the airline have the following operating profits:

$$\pi_t = (p_t - c_t)q_t(p_t,p_a), \tag{9}$$

$$\pi_a = (p_a - c_a)q_a(p_t,p_a), \tag{10}$$

where marginal (operating) cost per passenger by train and air are denoted by c_t and c_a, respectively.

We are concerned with the external costs transport modes are imposing on society. These costs are proportional to the number of users and each mode has a different negative impact. Given that, we define the damage function as $D = \sum_i \delta_i q_i$, for $i = t, a, c$ where δ_i is interpreted as the per unit damage imposed by mode i. Finally, define the (gross of damages) social welfare function (SW) as the sum of consumer surplus (CS) and industry profits (Π),

$$\begin{aligned} SW &= CS + \Pi = U - p_tq_t - p_aq_a - r_cq_c + \pi_t + \pi_a \\ &= \left(\alpha_t - c_t - \frac{\beta_t}{2}q_t\right)q_t + \left(\alpha_a - c_a - \frac{\beta_a}{2}q_a\right)q_a \\ &\quad + \left(\alpha_c - r_c - \frac{\beta_c}{2}q_c\right)q_c - \gamma(q_tq_a + q_tq_c + q_aq_c). \end{aligned} \tag{11}$$

The effect on society of the policy analyzed will be assessed as the difference in the sum of SW and damages D that such a policy will induce.

[2] For example, [37] emphasize the relevance of train speed and note that its effect is more important for short-haul routes where airline and HSR services are stronger competitors.

[3] All a_k are assumed positive, that is $min\{\alpha_t, \alpha_a\} > \frac{\gamma}{\beta_c}(\alpha_c - r_c)$. Also, it happens that $b_k > d$ because $\beta_i\beta_j > \gamma^2$ for all $i, j = t, a, c, i \neq j$.

3.1. The benchmark scenario: the duopoly equilibrium

Consider that the HSR operator and the airline compete in prices, so each operator chooses p_t and p_a to maximize its corresponding profits in (9) and (10). The solution of the system $\frac{\partial \pi_t}{\partial p_t} = 0$ and $\frac{\partial \pi_a}{\partial p_a} = 0$ and the equilibrium condition $q_c = \frac{1}{\beta_c}(\alpha_c - r_c) - \frac{\gamma}{\beta_c}(q_a + q_t)$, where superscript d stands for duopoly, yields

$$p_t^d = a_t - \frac{b_t(2b_a(a_t - c_t) + d(a_a - c_a))}{4b_tb_a - d^2}, \tag{12}$$

$$p_a^d = a_a - \frac{b_a(2b_t(a_a - c_a) + d(a_t - c_t))}{4b_tb_a - d^2}. \tag{13}$$

Once the equilibrium prices are obtained, the equilibrium quantities read,

$$q_t^d = \frac{b_a\left(\left(2b_tb_a - d^2\right)(a_t - c_t) - b_td(a_a - c_a)\right)}{\left(4b_tb_a - d^2\right)\left(b_tb_a - d^2\right)}, \tag{14}$$

$$q_a^d = \frac{b_t\left(\left(2b_tb_a - d^2\right)(a_a - c_a) - b_ad(a_t - c_t)\right)}{\left(4b_ab_t - d^2\right)\left(b_tb_a - d^2\right)}, \tag{15}$$

$$q_c^d = \frac{\alpha_c - r_c}{\beta_c} - \frac{\gamma}{\beta_c}\left(q_t^d + q_a^d\right). \tag{16}$$

Let us define $R = \frac{a_t - c_t}{a_a - c_a}$. This ratio can be interpreted as the relative premium of the willingness to pay net of marginal costs between HSR and air transport services. The term premium meaning, as indicated in the definitions of a_t and a_a, the advantage of each mode over the net willingness to pay for private car use. Then, $R > 1$ is interpreted as a relative preference for the HSR service over air travel. Equilibrium quantities are required to be positive, which translates to the following restriction on R, $\frac{b_td}{2b_tb_a - d^2} < R < \frac{2b_tb_a - d^2}{b_ad}$; and $q_t^d + q_a^d < \frac{\alpha_c - r_c}{\gamma}$.

3.2. The short-haul flights ban scenario: the monopoly equilibrium

Suppose now that a no-flights policy is implemented so that the airline can no longer operate this route. The HSR maximizes profits taking into account that now users' equilibrium condition for the car use becomes $q_c = \frac{\alpha_c - r_c - \gamma q_t}{\beta_c}$ and the HSR inverse demand function in (5) now reads $p_t(q_t) = a_t - b_tq_t$. The equilibrium quantities in this case are

$$q_t^m = \frac{a_t - c_t}{2b_t}, \tag{17}$$

$$q_c^m = \frac{\alpha_c - r_c}{\beta_c} - \frac{\gamma}{\beta_c}q_t^m. \tag{18}$$

3.3. The effects of the no-flights policy

In this section we first find the condition for the no-flights policy to imply higher damages and then its effect on the gross of damages social welfare, as well as on consumer surplus and total profits. Remind that $D^d = \delta_tq_t^d + \delta_aq_a^d + \delta_cq_c^d = (\delta_t - \frac{\gamma}{\beta_c}\delta_c)q_t^d + (\delta_a - \frac{\gamma}{\beta_c}\delta_c)q_a^d + \frac{\alpha_c - r_c}{\beta_c}\delta_c$, while $D^m = \delta_tq_t^m + \delta_cq_c^m = (\delta_t - \frac{\gamma}{\beta_c}\delta_c)q_t^m + \frac{\alpha_c - r_c}{\beta_c}\delta_c$. The effects of a no-flights policy on damages will be negative if $D^m > D^d$. The condition for $D^m > D^d$ can be written as follows,

$$\delta_c > \frac{\beta_c}{\gamma}(\Gamma_a(R)\delta_a - \Gamma_t(R)\delta_t), \tag{19}$$

where $\Gamma_a(R) = \frac{2b_t^2((2b_ab_t - d^2) - b_adR))}{H}$, $\Gamma_t(R) = \frac{d(2b_ab_t^2 - d(3b_tb_a - d^2)R)}{H}$ and $H = 2b_t^2(2b_ab_t - b_ad - d^2) - (2b_ab_t^2 - 3b_ab_td + d^3)dR$.

Note that, $\Gamma_a(R) > 0$ while $\Gamma_t(R) > 0$ only if $R < \frac{2b_t^2b_a}{d(3b_tb_a - d^2)} < \frac{2b_tb_a - d^2}{b_ad}$.

Condition (19) imposes a sufficiently large δ_c for the no-flights policy to imply a larger damage. Considering $\delta_a > \delta_t$, this condition is weaker, i.e. the right-hand side of (19) is smaller, the larger R, that is, the larger the relative premium of the HSR upon the air transport. Similarly, condition (19) is weaker the larger b_a if $R < \frac{b_t}{d} < \frac{2b_tb_a - d^2}{b_ad}$ and the smaller b_t if[4] $\frac{b_td}{2b_tb_a - d^2} < r^- < R < \frac{2b_tb_a - d^2}{b_ad}$. We summarize the above results in the following Proposition:

Proposition 1. Damages increase with a no-flights policy for a sufficiently large δ_c, as indicated in condition (19). Given, $\delta_a > \delta_t$, the condition is weaker: .

i) the higher the relative preference for the HSR upon the air transport.
ii) the larger b_a for small enough relative preference for the HSR upon the air transport; and iii) the smaller b_t.

To give a simpler condition we assume symmetry as follows. Firstly, symmetry in the HSR and air modes, which entails, $a_a = a_t = a = \alpha - \frac{\gamma}{\beta}(\alpha_c - r_c)$, and $c_a = c_t = c$; this implies that $q_t^d = q_a^d = q^d$ and $R = 1$. Also symmetry in substitution across modes, since we assume $\beta_t = \beta_a = \beta_c = \beta$. Then, condition (19) now simplifies to,

$$\delta_c > \frac{\beta}{\gamma}\left(\frac{2(\beta + \gamma)^2\delta_a - \beta\gamma\delta_t}{2\beta^2 + 3\beta\gamma + 2\gamma^2}\right). \tag{20}$$

The above condition is weaker when modes are better substitutes for $\delta_a > \delta_t$.

Finally, a sufficient condition for the no-flights policy to imply larger damages is obtained by setting $\delta_t = 0$,

$$\frac{\delta_c}{\delta_a} > \frac{\beta\left(2(\beta + \gamma)^2\right)}{\gamma\left(2\beta^2 + 3\beta\gamma + 2\gamma^2\right)} > 1. \tag{21}$$

Then, if the relative per unit damage of the road and air modes is sufficiently larger than one, the no-flights policy will induce damages. This requirement decreases with the degree of substitution across modes. For instance, in case $\gamma = \beta$, that is, users view modes as perfect substitutes, the no-flights policy induces larger damages when $\frac{\delta_c}{\delta_a} > \frac{8}{7}$.

Consider now the effect on SW, CS and Π. First note that in the case of symmetry, i) $q_c^d = \frac{\alpha_c - r_c}{\beta} - \frac{\gamma}{\beta}(q_t^d + q_a^d)$, $q_t^d = q_a^d = q^d = \frac{\beta(\beta+\gamma)(a-c)}{(\beta-\gamma)(2\beta+\gamma)(\beta+2\gamma)}$, and ii) $q_c^m = \frac{\alpha_c - r_c}{\beta} - \frac{\gamma}{\beta}q_t^m$, $q_t^m = q^m = \frac{\beta(a-c)}{2(\beta^2 - \gamma^2)}$. All the above equilibrium quantities are positive if and only if $\frac{\gamma}{\beta} < \frac{a-c}{\alpha_c - r_c} < \frac{2\beta^2 + 3\beta\gamma - \gamma^2}{2\gamma(\beta+\gamma)}$. Therefore, it happens that $q^d < q^m < 2q^d$ which implies that the modal split changes to more train users ($q_t^m > q_t^d$) and more traffic on the road ($q_c^m > q_c^d$) when there is a ban. Besides, total traffic decreases, $2q^d + q_c^d > q^m + q_c^m$. This shift on the modal split leads to a reduction in SW, CS and Π. The SW expressions that correspond to each situation are obtained from (11) and read,

$$SW^d = \frac{(\alpha_c - r_c)^2 + 4(\beta(\alpha - c) - \gamma(\alpha_c - r_c))q^d - 2(\beta - \gamma)(\beta + 2\gamma)(q^d)^2}{2\beta}, \tag{22}$$

$$SW^m = \frac{(\alpha_c - r_c)^2 + 2(\beta(\alpha - c) - \gamma(\alpha_c - r_c))q^m - \left(\beta^2 - \gamma^2\right)(q^m)^2}{2\beta}. \tag{23}$$

Similarly for CS and Π,

[4] Note that r^- is the lower root for R of expression $4b_a^2b_t^3 - d\left(12b_a^2b_t^2 - 9b_ab_td^2 + 2d^4\right)R + (3b_a^2b_td^2 - 2b_ad^4)R^2 = 0$. In case of symmetry, $R = 1$ and $r^- < 1$ iff $0.761\beta < \gamma < \beta$.

$$CS^d = \frac{(\alpha_c - r_c)^2 + 2(\beta - \gamma)(\beta + 2\gamma)(q^d)^2}{2\beta}, \tag{24}$$

$$\Pi^d = \pi_t^d + \pi_a^d = \frac{2(\beta(\alpha - c) - \gamma(\alpha_c - r_c) - (\beta - \gamma)(\beta + 2\gamma)q^d)q^d}{\beta}, \tag{25}$$

$$CS^m = \frac{(\alpha_c - r_c)^2 + (\beta^2 - \gamma^2)(q^m)^2}{2\beta}, \tag{26}$$

$$\Pi^m = \pi_t^m = \frac{(\beta(\alpha - c) - \gamma(\alpha_c - r_c) - (\beta^2 - \gamma^2)q^m)q^m}{\beta}. \tag{27}$$

Proposition 2. Under symmetry in the HSR and air modes (that is, $a_a = a_t = a = \alpha - \frac{\gamma}{\beta}(\alpha_c - r_c)$, and $c_a = c_t = c$) and symmetry in the degree of substitution across modes (since $\beta_t = \beta_a = \beta_c = \beta$), the short-haul flight bans reduce social welfare gross of environmental damages, as well as consumer surplus and total profits.

To prove the above claim note that the signs of the differences $SW^d - SW^m$, $CS^d - CS^m$ and $\Pi^d - \Pi^m$ are given by same signs of the following polynomials, $12\beta^3 + 20\beta^2\gamma + 13\beta\gamma^2 - 2\gamma^3$; $4\beta^3 + 12\beta^2\gamma + 15\beta\gamma^2 + 6\gamma^3$ and $4\beta^3 + 4\beta^2\gamma - \beta\gamma^2 - 2\gamma^3$, which are definitely positive for $\beta > \gamma$.

If quantity competition among the HSR and the airline is assumed, a similar condition to that in (19) can be obtained. Considering full symmetry, the corresponding condition to (20) is $\delta_c > \frac{2\beta(\beta+\gamma)\delta_a - \beta\gamma\delta_t}{\gamma(2\beta+\gamma)}$, which is more demanding, so a larger δ_c is needed. A sufficient condition for larger damages under the no-flights policy becomes $\frac{\delta_c}{\delta_a} > \frac{2\beta(\beta+\gamma)}{\gamma(2\beta+\gamma)}$, which is decreasing in γ and larger than one, being $\frac{\delta_c}{\delta_a} > \frac{4}{3}$ when $\gamma = \beta$.

The above results confirm some of the intuitions suggested in the literature with regard to the unclear effects on damages and welfare related to the interactions that arise under modal competition. [11,12] conclude that damages may be larger and welfare lower when there is a new HSR line in competition with air transport. We reach similar conclusions moving in the opposite direction by adopting a market-based measure materialized as a short-haul flights ban. The main difference between these two approaches is that we explicitly consider the effect on private car traffic. Our analysis discloses the relevance of the size of per unit damages across all modes involved. In particular, it is sufficient for an increase in damages that the relative size of per unit damages between road and air transport be large enough. The policy implication that follows is that one should not only look at the market structure effect, but also evaluate the traffic redistribution effects that show up since each mode contribution to environmental damages is different. In the particular case of short-haul flights bans, policy makers might implement complementary measures that reduce the per unit damage of private car use with the goal of mitigating the likelihood of their detrimental environmental effects.

Table 1
Data for Madrid-Barcelona and Madrid-Valencia OD markets, year 2018.

	Madrid-Barcelona	Madrid-Valencia
HSR		
Kms by HSR	506	303
Price (euros)	80	55
Traffic (pass. per day and direction)	5879	3321
Air		
Kms by air	487	293
Price (euros)	100	85
Traffic (pass. per day and direction)	3382	495
Private transport (car)		
Kms by car	617	356
Price (euros)	60	40
Traffic (pass. per day and direction)	3041	8386

Source: AENA, RENFE, DG. of Transport, Ministry of Works and own elaboration.

4. An empirical application to Spain

Spain ranks first in Europe in terms of HSR network length, with 3622 km in 2021, and second globally after China (40,474 km). Spanish HSR services provide speeds of up to 300 km/h with short travel times, multiple frequencies and stations in the city center. This represents a significant improvement in service quality and puts competitive pressure on air transport for distances between 300 and 700 km. Since the official opening of the first lines, they have had a significant substitution effect on the air transport mode for medium to long distance routes, leading to a modal re-distribution of passenger transport. HSR is an important tool for meeting the commitments made to reduce GHG emissions from passenger transport in the European Union. Spain is therefore a good example to ex-ante evaluate the effects of banning short-haul flights.

We present the calibration of effects of bans in two OD markets. The first one is the Madrid-Barcelona corridor, the most important OD market with 9.40 million travelers in 2018 (8.24 million in the period 2005–2018). The two cities have Spain's two largest airports, there is a highway connecting the two cities and a HSR service has been in operation since February 2008. It is important to note that the modal split in 2018 was 45.7% HSR, 26.3% air, 23.6% private car. This means that the market is dominated by HSR, a situation that has been reached from an initial dominance of air transport of 43.4% in 2008, which indicates an important modal shift in favor of HSR. The distance traveled per mode is different as shown in Table 1. The in-vehicle time ranges from one hour twenty minutes by air to two hours forty minutes by HSR and five hours fifty minutes by car. The air journey requires at least one hour for check-in and security control. The fastest way to reach Madrid airport is a 30 min cab trip. Similar times are spent at the destination airport. Finally, there is an average schedule delay of forty five minutes, since there are 24 flights per day and we consider eighteen hours per day. Therefore, the total travel time by air is over four hours. Likewise total travel time by HSR is around five hours (including one hour access/egress time plus one hour twenty minutes of average schedule delay). Thus, the three modes are reasonable alternatives for an average user.

The second market is the Madrid-Valencia corridor, which links the first and third Spanish cities in terms of population. It is the second OD market with 9.24 million travelers in 2018 (8.72 million in the period 2005–2018). Valencia has a major international airport, there is a highway connecting both cities and a HSR service has been operating since December 2010. However, in 2018 the Madrid-Valencia market was dominated by private car, 66.2%, followed by HSR, 26.2% and by air, 3.9%. Since the HSR started operating, the shares of air and private car have decreased from 11.1% and 76.0%, respectively. In this case, the in-vehicle time ranges from one hour five minutes by air to one hour fifty minutes by HSR and three hours twenty minutes by car. Adding up check-in and security control as above plus fifty minutes cab trips, plus an average schedule delay of two hours thirty five minutes (only seven flights per day) make for a total travel time by air of five hours thirty minutes. Likewise total travel time by HSR is around four hours twenty minutes (including one hour access time plus one hour thirty minutes of average schedule delay). The preceding discussion might well explain the prevalence and use of car in this route.

Although coaches are a viable alternative in some countries, in neither of the Spanish OD markets we consider coaches have a significant presence. They represent 4.4% in Madrid-Barcelona and 2.2% in Madrid-Valencia. Otherwise, it would be important to track the impact

Table 2
Own and cross price elasticities.

	HSR	Air transport	Car transport
HSR	– 0.65	0.39	0.21
Air transport	0.39	– 1.22	0.25
Car transport	0.21	0.25	– 0.50

Source: [29,25] and [31].

that the deregulation of bus services may have on intermodal competition in long-distance land passenger transport [4].[5]

Therefore, we present two OD examples where the HSR has been important in reducing air transport, but this mode is dominant only in the former market. This difference will prove important in explaining the impact of the short-flights ban on society. Information of these two corridors for 2018 appears in Table 1.

We proceed to calibrate the model following the methodology employed in [2,1]. In this exercise we will apply a more general version of the utility function in (1), where cross parameters between transport modes will be different. To find values for the parameters in the utility function, values on prices, traffic levels and price elasticities have been used as a reference. Values for own and cross price elasticities are displayed in Table 2.

The values for elasticities are borrowed from different references. The literature obtains similar values for own price elasticities, where clearly air transport is price elastic, with values slightly higher than one, HSR presents a price elasticity around (– 0.6, – 0.7) and car transport is the most inelastic mode. Regarding cross-elasticities there is a higher dispersion in the values. [29] estimate a higher cross sensitivity than [25] and [31]. We have opted to consider a mean value for the cross-elaticities, and a sensitivity analysis will be undertaken in order to provide more robustness to our results. In particular, the values obtained for the parameters of the utility function for both corridors are shown in Table 3. Note that in the Madrid-Barcelona corridor the different parameter types are more similar across modes, indicating that this corridor is closer to the symmetric case in the theoretical model.[6] Regarding operating transport costs, we employ data for the cost per passenger by HSR and air in both corridors, which are displayed in Table 4.

Finally, in order to incorporate the external costs in our model we will use the definition of external costs and the estimates employed in the Handbook elaborated by the EU (see "Handbook on the external costs of transport", version 2019–1.1). The total external costs for road, rail, inland waterway transport, aviation and maritime in 2016 amounted to €987 billion, which corresponds to 6.6% of total GDP in EU28. Road transport is by far the mode that causes most external costs, 83% of the total costs (out of this 83% around 69% is due to passenger transport). Aviation causes 10%, while rail transport 1.8%. In particular,

Table 3
Calibrated utility function parameters.

	Madrid-Barcelona	Madrid-Valencia
β_t	0.016	0.039
β_a	0.019	0.362
β_c	0.032	0.036
γ_{ta}	0.0091	0.083
γ_{tc}	0.0093	0.028
γ_{ac}	0.0103	0.096
α_t	261.83	500.31
α_a	250.02	1359.57
α_c	226.67	474.11

Table 4
Operating costs per transport mode and OD market.

	Madrid-Barcelona	Madrid-Valencia
Operating costs HSR	65	45
Operating costs air	80	65

Source: Own elaboration from [8] and [35].

we will follow two approximations. In the first one we consider only external costs of environmental type. In this case we take into account the effects of pollution, climate change, well-to tank and congestion. We assume that congestion not only results in more travel time and energy consumption, but also causes pollution, decreases productivity and imposes costs on society. During congestion, vehicles spend more time on the road, idling or crawling, and undergo numerous acceleration and deceleration events that may lead to an increase in emissions, see [32]. In the second approximation we include all the external costs provoked by transport. Then we add to the former costs, the external costs in terms of accidents, noise and habitat damage. Table 5 displays the values of these external costs in cents of € per passenger-km.

Results for the simulation for both corridors are reported in Table 6. Note that there are two columns for each OD market, one for the case where air transport competes with HSR and car, and another one where air transport is banned.

In the case of Madrid-Barcelona (columns two and three), note that banning short-haul flights would suppose an increase in HSR price by 15.5% and by 4.6% in rail traffic. This is explained by the elimination of a direct competitor for the HSR. At the same time the removal of air transport would lead to a rise by 33.1% in the use of private car. Note that car traffic behaves as a competitive mode and the cost of private car use remains fixed not reacting to the removal of air transport, but it becomes relatively cheaper than HSR service. There is a modal redistribution from air to HSR and, specially, to car use, although total traffic falls by 17.1%, following the elimination of short-haul flights. It is clear that the HSR operator will improve her profits with the air transport ban, but user surplus will notably fall by 19.7%, and gross social welfare also falls by 14.8%. Regarding external costs, when only external environmental costs were considered the banning of flights would reduce the

Table 5
External costs per transport mode in cents of € per pass-km.

	HSR	Air (short-haul)	Car transport
Air pollution	0.0	0.30	0.7
Climate	0.0	2.39	1.2
Congestion	0.0	0.00	4.2
Well-to-Tank	0.3	1.06	0.4
External environm. costs	**0.3**	**3.75**	**6.5**
Accidents	0.1	0.04	4.5
Habitat damage	0.6	0.03	0.5
Noise	0.3	0.46	0.6
Total external costs	**1.3**	**4.28**	**12.1**

Source: EC DG for Mobility and Transport "Handbook on the external costs of transport", 2019.

[5] There is also a residual presence of conventional rail services that amount to 0.1% and 1.5% of total travelers, respectively. We consider traditional combustion cars, excluding electric cars, since in 2018 the percentage of electric passenger cars in Spain was 0.11% over the total number of cars (26,800 vehicles); the percentage rises to 1.1% (238,329) if we consider non-plug-in hybrids [3]. The charging infrastructure, on the other hand, only had 8673 public charging points at the end of 2019, of which 6624 were located in metropolitan regions [26]. All this makes the electric car practically non-existent as a viable alternative for the time being. Note, however, that the consideration of coaches and electric cars can be easily introduced in our analysis.

[6] Using the utility function parameters in Table 3, we find that the degree of product differentiation between modes (i.e. $\frac{\gamma_{ij}^2}{\beta_i\beta_j}$) in the Madrid-Barcelona corridor are very similar, the three are in the range 0.169–0.272; while for the Madrid-Valencia corridor the degree of product differentiation is lower between the road and the air, 0.621; while those for the other modes are close to zero. Further note that the calibrated parameters in Table 3 are compatible with the concavity of the utility function.

Table 6
Simulated effects of the no-flights policy for Madrid-Barcelona and Madrid-Valencia OD markets.

	MADRID-BARCELONA		MADRID-VALENCIA	
	HSR+Air	Flights Ban	HSR+Air	Flights Ban
HSR price	111.54	128.87 15.54%	93.33	95.37 2.19%
Air price	99.46		98.50	
HSR traffic	5879	6152 4.64%	3321	3375 1.63%
Air traffic	3382		495	
Car traffic	3041	4047 33.08%	8386	9686 15.50%
Total traffic	12,302	10,199 − 17.09%	12,202	13,061 7.04%
HSR operat. profits	361,812	485,184 34.10%	177,111	186,840 5.49%
Airline operat. profits	150,380		24,026	
User surplus	980,261	786,747 − 19.74%	2829,055	2810,061 − 0.67%
Gross Social Welfare	1492,450	1271,930 − 14.77%	3030,170	2996.900 − 1.10%
Ext. environ. costs	192,655	171,661 − 10.90%	202,513	227,221 12.20%
Total external costs	333,236	339,523 1.89%	379,524	429,540 13.18%

environmental damages by 10.9%, which is a positive result. However, if we took into account all external costs there would be a small increase by 1.9%. The reason for this result is that total external cost per pass-km of car is almost three times the total external cost of air; note that external costs due to accidents are particularly large for the car mode. Therefore, if total external costs were taken into account, these would increase with the banning of the air transport leading to net social welfare losses. Indeed, even with the most restrictive definition of external costs, the net social welfare is considerably reduced by 15.3% were short-haul flights banned, reaching 19.6% when all external costs are included.

Regarding results for Madrid-Valencia (columns four and five), we must first stress that in this corridor the presence of the air transport is much lower than in Madrid-Barcelona. In particular and considering only the largest modes of transport, HSR, air and car; the market share for air transport in Madrid-Barcelona was 29.0%, while the corresponding market share for air in Madrid-Valencia was 4.2%. In this corridor the increase in HSR price is very small (2.2%), and the increase in the HSR traffic is also very modest (1.6%). However, there is a notable rise in car traffic (around 15.5%), which is the worst mode in terms of total external costs. Therefore, there is a small substitution effect towards HSR and a notable one towards car use, yielding a 7.0% increase in total traffic, which is in contrast with what happens with Madrid-Barcelona.[7] In this case user surplus is reduced, but in a very small amount (only by 0.7%). Also gross social welfare falls by a small amount (1.1%) and welfare net of external cots falls by 3.1%. But now environmental external costs and total external costs are clearly higher with respect to the benchmark scenario. The increase in dominance of car transport is the main reason that explains that external costs are always higher after the banning of the air transport, which inevitably results in welfare losses net of external cost of 3.1%. It should be noted that the same qualitative effects arise in case of not allowing total traffic to increase following the ban. In particular, environmental costs increase by 2.4%, user surplus decreases by 1.1%, and finally, welfare net of external costs falls by 2.1%.

Since the prohibition of short-haul flights is controversial, there are alternative measures leading to similar environmental results that our simulation analysis allows. For instance, a reduction in the air environmental external cost per pass-km that would achieve the same reduction in environmental damages as the short-haul flights ban in the Madrid-Barcelona corridor. In this exercise, about a 40.0% reduction in δ_a would be needed to get the same reduction of environmental damages (that is, 20,994 euros per day and direction) due to the ban. Since in the Madrid-Valencia corridor both measures of external costs increase, the interesting question to be considered is the introduction of a complementary measure to the ban that may undo its undesirable effects on damages. For instance, measures that reduce the car environmental external cost per pass-km. In particular, a reduction by 11.0% in the car environmental external cost per pass-km is required to compensate for the increase in external environmental damages due to the ban. Similarly, a reduction by 12.0% reduction in total car external cost per pass-km is needed to compensate for the increase in total external damages due to the ban.

4.1. Robustness analysis

Results presented in Section 3 emphasize the relevance of the degree of product differentiation between transport modes in assessing the welfare effects and damages stemming from a short-haul flights ban. Fig. 1 and Fig.2 in the Appendix show the results when two of the γ are kept fixed at their calibrated values and the other is allowed to vary $\pm$ 7.5%, where a positive increase is interpreted as a reduction in the degree of product differentiation. The first row shows how percentage changes in γ_{ac} affect percentage variations in the relevant variables. In particular, the left panel displays HSR price and car traffic percentage changes; the middle panel displays external environmental (EEC) and total external costs (TEC) percentage changes; and finally, the right panel displays percentage variation of the user surplus (US), gross welfare (GSW) and welfare net of total external cost (NSW). The second and third rows follow the same pattern for changes in γ_{ta} and γ_{tc}, respectively. It is important to underline that the results in Table 6 are robust to changes in the degree of product differentiation in the three transport modes, since all percentage variations have the same sign in the interval of variation for each γ. Sizes of such variations depend in different ways for every γ. For example, in the Madrid-Barcelona market, total external costs increase by more and environmental costs decrease by less when γ_{ac} and γ_{ta} increase, while total external cost increase by less and environmental costs decrease by more when γ_{tc} increases. Similarly, gross social welfare and welfare net of total external costs decrease by less when γ_{ac} and γ_{ta} increase, while both measures of welfare decrease by more when HSR and car are less differentiated. Thus, measures that would involve making air transport less differentiated from the other modes reflect that environmental damages decrease by less but welfare losses are not so accentuated. Finally, the percentage increase in HSR prices due to a short-haul flights ban is lower when car becomes less differentiated with HSR and air, while the increase in larger if γ_{ta} increases. Therefore, regarding the effect on HSR prices measures that make the private car more similar to the other modes in the eyes of users would be welcomed. In the case of the Madrid-Valencia market, gross social welfare and welfare net of total external costs behave in the same qualitative way as in the Madrid-Barcelona corridor. However, total external costs and environmental costs decrease by less when γ_{ac} and γ_{ta} increase, while both measures of external cost increase by more when γ_{tc} increases.

We also provide in Fig. 3, a sensitivity analysis referred to the cost of private car. That is, whether our results depend on the relative price between the use of car and the use of modes provided by firms. Our first

[7] A condition for total traffic under the ban be larger can be obtained as follows. Car traffic before the ban is $q_c^d = \frac{\alpha_c - r_c - \gamma_{ac} q_a^d - \gamma_{tc} q_t^d}{\beta_c}$, and total traffic, $Q^d = q_c^d + q_a^d + q_t^d = \frac{\alpha_c - r_c}{\beta_c} + \frac{\beta_c - \gamma_{ac}}{\beta_c} q_a^d + \frac{\beta_c - \gamma_{tc}}{\beta_c} q_t^d$. Similarly, when the ban is implemented, total traffic is $Q^m = q_c^m + q_t^m = \frac{\alpha_c - r_c}{\beta_c} + \frac{\beta_c - \gamma_{tc}}{\beta_c} q_t^m$. Thus, $Q^m > Q^d$ if and only if $\frac{q_t^m - q_t^d}{q_a^d} > \frac{\beta_c - \gamma_{ac}}{\beta_c - \gamma_{tc}}$. Using the values in Table 3 for Madrid-Valencia and those for the corresponding $q's$ in Table 6, columns 4 and 5, we find $Q^m > Q^d$, while if we check it for the Madrid-Barcelona corridor, it happens that $Q^m < Q^d$.

comment is that the model is robust to variations in r_c, that is, both welfare accounts and user surplus are lower after the ban in the two routes and their decreases are more important the larger r_c is. Also in both routes, total external costs increase after the ban and are more marked for larger values of r_c. For the environmental external costs, the effect of a larger r_c is that damages increase by more in the Madrid-Valencia route, while they are reduced by more in the Madrid-Barcelona route. To end, note that although car users decrease when the cost of private car increases, we find that the effect of the ban is to increase car traffic in both routes and this increase becomes larger for larger values of r_c. That meaning that the effect of an increase of r_c is more pronounced before the ban. Another issue is that the cost of private car will increase after the implementation of the ban, either exogenously by the introduction of highway tolls or endogenously by the increase in road congestion. In both cases, the after-ban car traffic will be less as compared to the figures that appear in Table 6.

One of the unwanted side effects of the short-haul flights ban is the expected increase in HSR prices that leads to a reduction in user surplus. One way to fix it is to use a price regulation measure by imposing a cap on HSR price. Another alternative, that goes in the same direction is to introduce competition in HSR services. Therefore, one wonders whether the increase in availability of a more environmental friendly mode may reverse our main conclusions. It is therefore worth analyzing the effects of a second HSR competitor. In 2018 this was not possible, because only the incumbent operator (RENFE) offered HSR services. However, as of 2022, some new private operators (OUIGO and Iryo) have entered in Madrid-Barcelona and Madrid-Valencia corridors. Consequently, we have simulated the existence of a duopoly in the HSR service assuming that HSR companies are symmetric and that the degree of differentiation between HSR services is lower than across modes. The results for the two corridors are in Table A.1 in the Appendix. Focusing on the corridor Madrid-Barcelona, the removal of flights would lead to a lower increase in HSR prices and car traffic, a larger increase in HSR traffic, and a larger reduction in external environmental costs with respect to the situation of only one HSR operator. However, if all the external costs are considered the removal of flights would lead to a small decrease in total external costs, the reason being that HSR competition leads to lower prices for air and rail transport, thus the share of car traffic is lower as compared to the case with only one HSR service. Also, a ban on flights induces a lower increase in car use and a larger increase of HSR traffic with respect to Table 6. Besides, the reduction in the user surplus would be very much lower than that produced in the rail monopoly situation. The reason is that users suffer less after a flights ban when there is competition in HSR services because HSR prices increase by less. In terms of profits, HSR duopolists capture the foregone profits of air transport. Finally, net social welfare decreases by less. Regarding the Madrid-Valencia corridor, in the case that there are two HSR companies the results are very similar to the case of the rail monopoly. User surplus is hardly affected due to the relative low market share of air transport. The removal of flights will lead to a relevant increase in the environmental and all the external costs and ultimately in a lower net social welfare loss than in the case of no HSR competition.

5. Concluding remarks and policy implications

The fact that global air transport significantly affects climate change has prompted scholars to develop studies that evaluate policy measures towards a greener modal split. One such measure is the promotion of rail above air travel, which emits less greenhouse gases per passenger. This is a possibility in short distance routes where rail and air transport effectively compete. Our paper has formally explored the welfare and external environmental consequences of a short-haul flights ban, a market-based policy that is being implemented or planned in several European countries. The analysis carefully considers the demand effects between air, rail and private car transport while taking into account a number of external costs associated to each mode. The main conclusion from our theoretical analysis is that, provided that the per unit external cost of road transport is sufficiently large, a no-flights policy is detrimental to society as it generates larger external costs. The simulation results for two Spanish corridors suggest that, although there may be less external environmental costs in the route with more air traffic, there are always losses to society; users are worse off and total external costs increase. Increases in environmental external costs cannot be ruled out. The size of such losses is found to depend on the degree of differentiation between modes and the existence of competition in rail services.

Some relevant policy implications can be drawn from our analysis regarding the desirability of a short-haul flights ban. Firstly, in view of our results, a blanket approach for such a policy should not be adopted; we propose a careful case-by-case study. Secondly, complementary measures would be advisable. One of them would be to encourage more fuel efficient cars to lessen the negative effects of the policy. Another complementary measure is to use short-haul flights as the means to extent the adoption of SAF (sustainable aviation fuel) on aviation via subsidies; this will enhance the use and improvement of such technology by moving forward on the learning-by-doing curve. In fact, technological improvements could result in environmental costs reductions that are equivalent to banning short-haul flights. Finally, an alternative policy would consist of the improvement of HSR service quality and/or on-track competition to make it relatively more attractive to users. This would provide for a better initial setting in which to consider policies that limit short-haul flights.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

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Appendix A. Figures and Table for the robustness analysis

Table A.1
Simulated effects of the no-flights policy for Madrid-Barcelona and Madrid-Valencia OD markets with two symmetric HSR operators.

	MADRID-BARCELONA		MADRID-VALENCIA	
	HSR+Air	Flights Ban	HSR+Air	Flights Ban
HSR price	93.96	101.44 7.96%	78.53	79.62 1.39%
Air price	85.51		90.84	
HSR traffic per firm	5009	5469 9.18%	2946	3004 1.97%
Air traffic	2666		420	
Car traffic	2072	2661 28.43%	6543	7590 16.00%
Total traffic	14,756	13,599 − 7.84%	12,855	13,598 5.78%
HSR op. profits per firm	220,206	281,306 27.75%	113,487	119,021 4.87%
Airline operat. profits	81,351		17,633	
User surplus	1253,517	1125,497 − 10.21%	2945,470	2930,266 − 0.52%
Gross Social Welfare	1856,636	1688,108 − 9.07%	3189,600	3173,310 − 0.51%
Ext. environ. costs	146,973	123,303 − 16.10%	161,377	181,102 12.22%
Total external costs	271,053	265,040 − 2.22%	308,537	348,807 13.10%

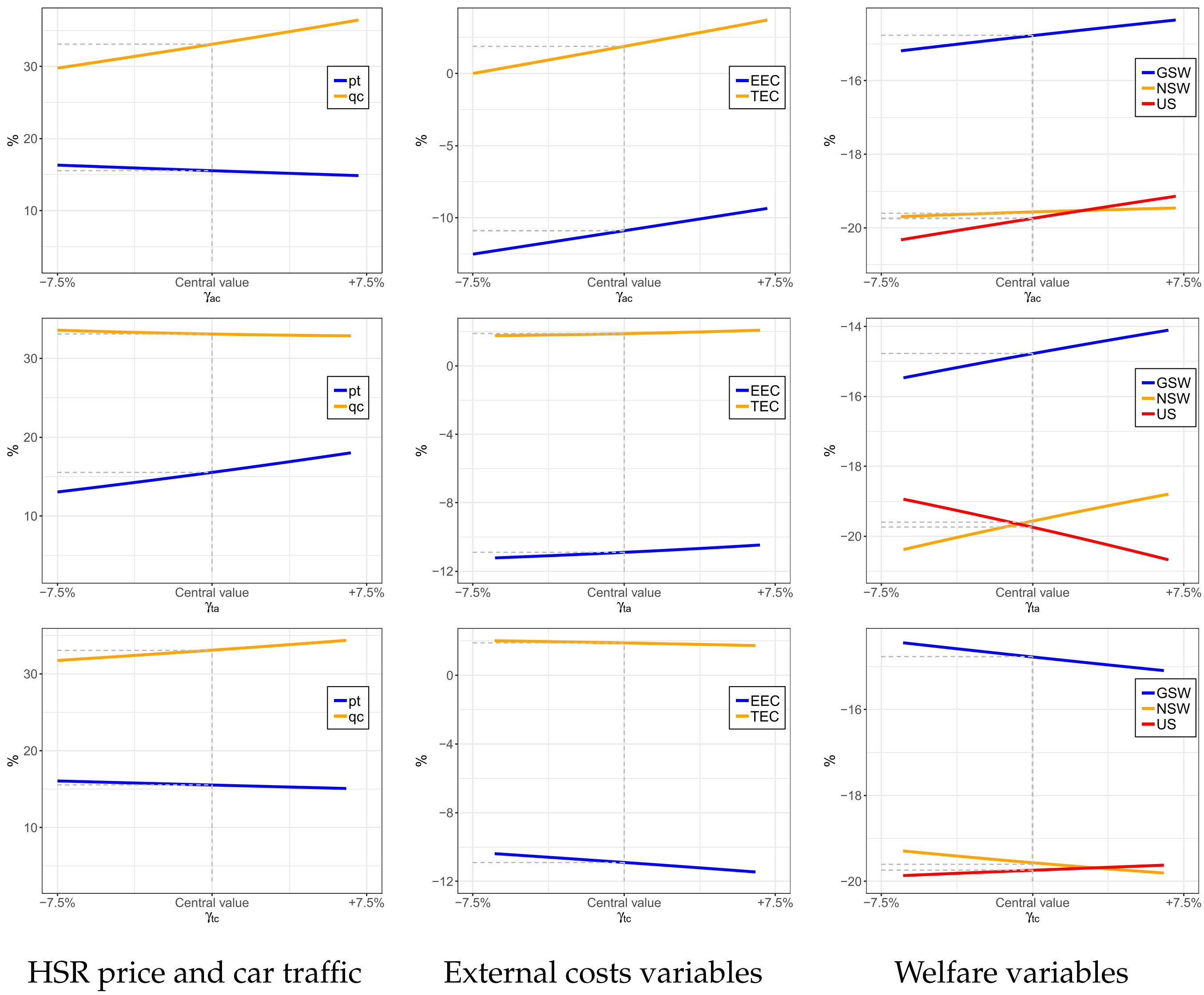

Fig. 1. Sensitivity for γ parameters for the Madrid - Barcelona market.

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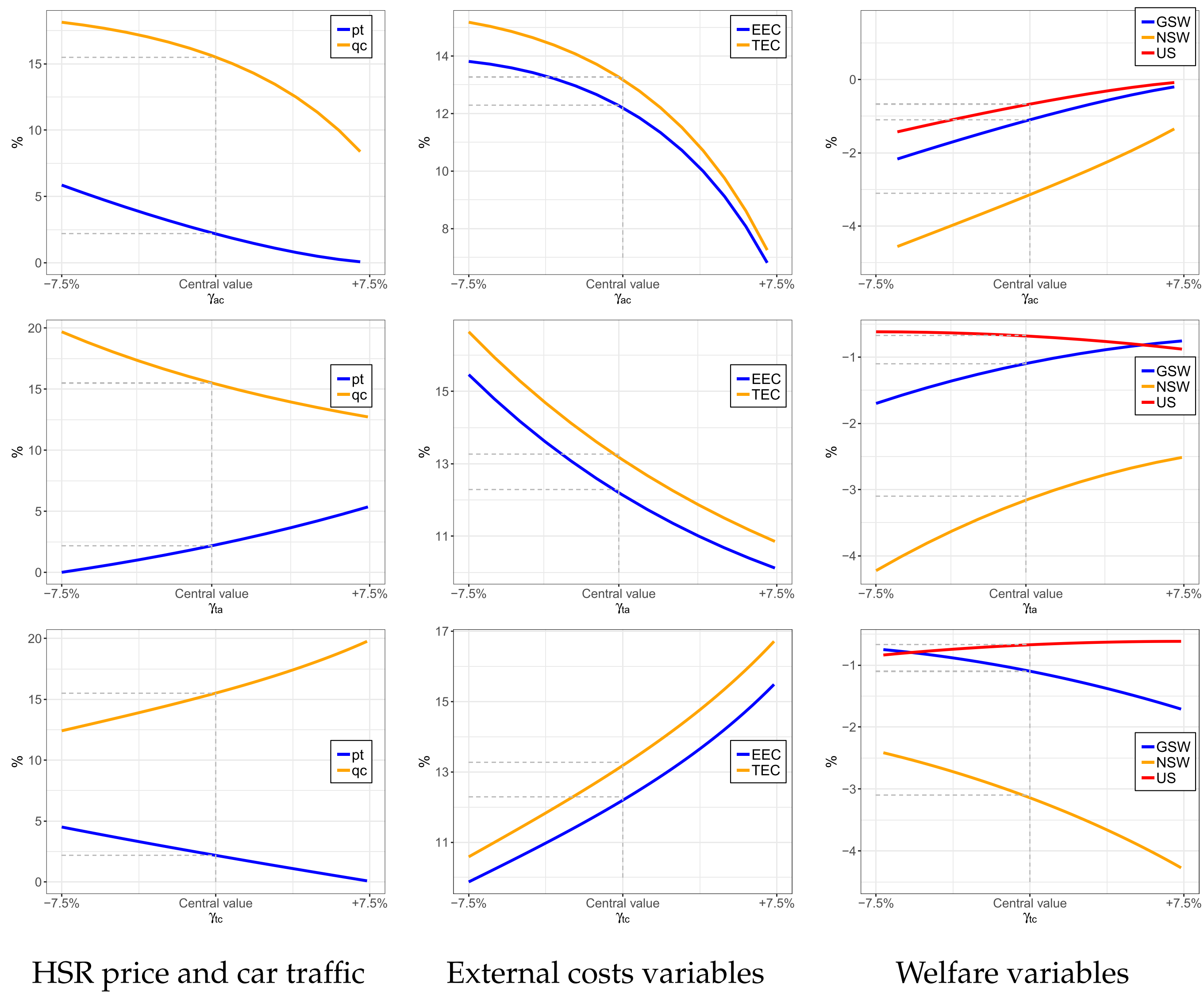

Fig. 2. Sensitivity for γ parameters for the Madrid - Valencia market.

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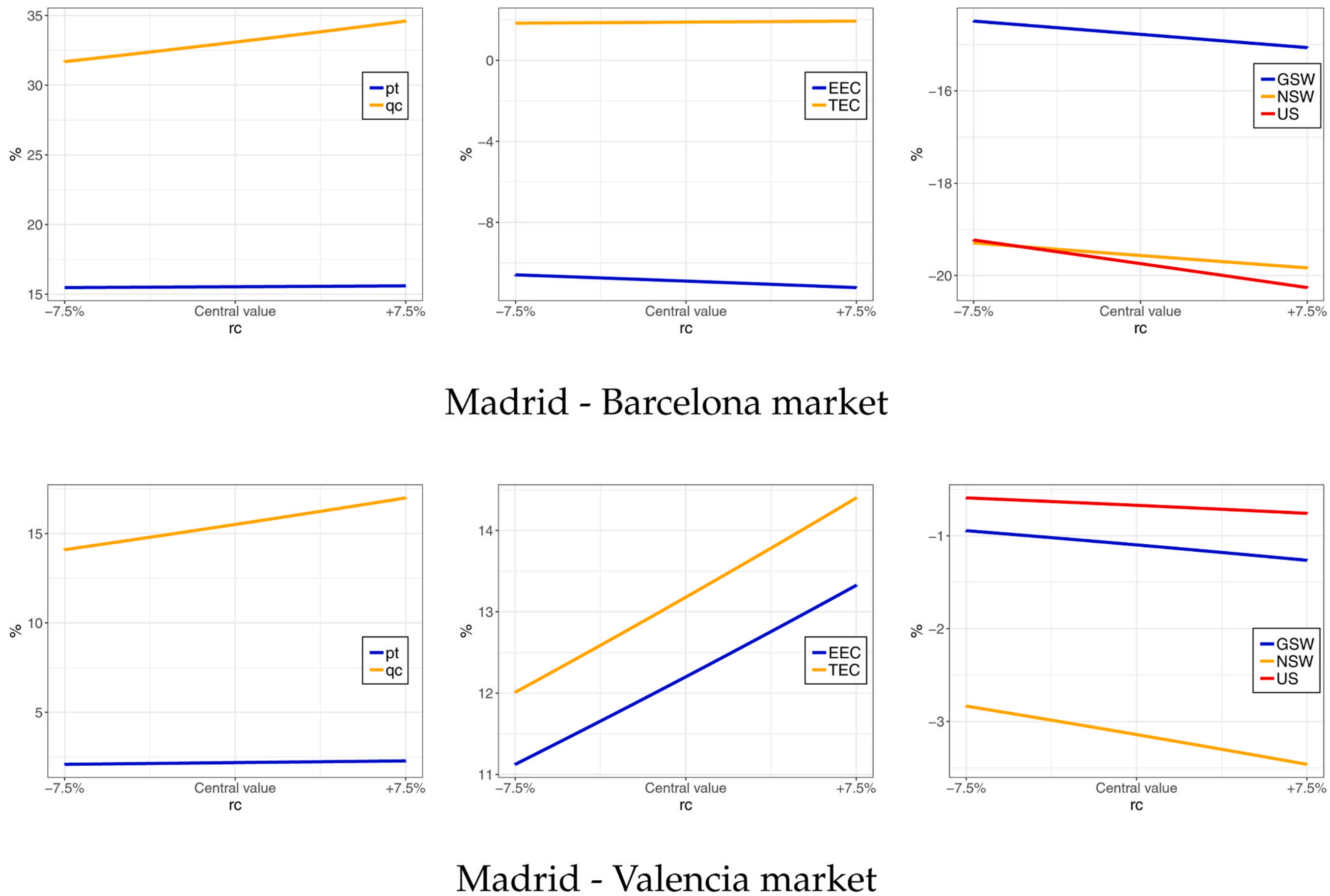

Fig. 3. Sensitivity for r_c.

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