Optimal environmental policy in air transport markets*

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May 2010

Abstract

Air transport services are essential in modern economies though they produce some important negative externalities. Air quality, greenhouse gas emissions, and noise are the main issues. Although most externalities found in air transport have a negative impact, there may be also a positive effect: the so-called impact on the "schedule delay". In this paper we show that the optimal ranking of policies may strongly depend on whether regulators act or do not act in a myopic way. Regulators act in a myopic way when they do not take into account the effects that a particular environmental policy has on other air transport externalities such as changes in the schedule delay.

Keywords: environmental regulation, schedule delay, generalized price, frequency

JEL Classification: Q53, H23, L91

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* This paper is a revised version of the Working Paper FUNCAS No 308/2007. The usual disclaimer applies.

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1. Introduction

Air transport services are essential in modern economies allowing mobility of passengers and freight throughout the territory. It is an important economic activity contributing during 2007 145 billion euros to the EU GDP and employing more than 3 million workers (European Commission, 2009). Though the benefits of air transport are clear, the presence of negative externalities is also a well known fact.

Air quality, greenhouse gas emissions, and noise are the main issues. Regarding air quality, the main concern refers to the possible impact on humans' health from emissions such as oxides of nitrogen (NOx), volatile organic compounds and particulates.

The aviation impact on climate change stems from CO_2, NOx and contrails and cirrus clouds, with the main impact given by CO_2 emissions. Although air transport is not a main contributor to climate change, it has been estimated that it will account for 4 percent of total carbon dioxide emissions by 2050. Moreover, emissions from aircraft will be growing in spite of the technological progress due to the increase in traffic.

According to a study (IWW/INFRAS, 2004) at least as much as 18 million people in Europe are exposed to air transport noise. This figure includes all levels of noise considered that range from 55 to more than 75 decibels. Noise emissions of aircraft are mostly produced during take-off and landing procedures and its main impacts relate to annoyance and effects on human health.Although most externalities found in transport have a negative impact, there may be also a positive effect: the so-called impact on the "schedule delay". Passengers have a preferred departure time and dislike the "schedule delay", which is equal to the difference between the actual and preferred departure time (see, for example, Basso, 2008; Brueckner, 2004; Panzar, 1979; Schipper et al., 1998). Increases in frequency reduce the "schedule delay" and, hence, consumers' generalized price. Some authors argue that this positive effect of frequency on consumers' generalized price is similar to the Mohring effect that is usually applied in the bus industry (Mohring, 1972).[1]

Environmental regulation in transport often relies on two main types of policies. On the one hand, we can distinguish *command and control instruments*, which are intended to reduce the level and impact of the external effect. Examples of these mechanisms include, among others, setting output limits, restrictions on the type of technology and fuels used, fulfilment of 'cleaner' requirements and standards, etc. Alternatively, it is also possible to use *market related instruments*, such as taxes or subsidies aiming at reducing the externality level and hence its impact, forcing the operators to internalize the effects of their actions.

Command and control regulation has been extensively used in air transport markets, although market related instruments are starting to gain relevance (e.g. inclusion of aviation on the EU emission trading scheme). In a special study about noise for a sample of 643 airports around the world (Boeing, 2008), 11 different types of measures intended to reduce the impact of airplanes noise are identified. The study shows that most frequent measures intended to reduce noise are general abatement procedures with restrictions on run ups and the utilization of preferential runways. They are followed by the implementation of curfews. Finally, a relevant 20 percent of airports in the sample have opted for charging a noise fee, whilst, only a minority are applying emission charges. On the other hand, Morrell and Lu (2000) report that there are 16 countries and over 60 airports in the world which apply noise charges on commercial flights.

The policy approach that deals with externalities in air transport usually focuses on one externality at a time, ignoring the possible interactions among all externalities. Although policy measures usually have no intended effects on other externalities, in practice they do affect each other, sometimes in a proactive way, but some others counterproductively. For instance, if an airport authority decides to close the facilities during night periods in order

[1] See Betancor and Nombela (2002), or Pels and Verhoef (2002) for a further discussion.

to reduce noise, the level of noise will be reduced, but also the air pollution associated to landing and take off cycles; however, the same measure will have important repercussions upon users that will be offered less frequent flights and their schedule delay cost will be increased. Few works in the literature have explicitly considered such interaction among effects. Some exceptions are Parry and Bento, (2002) or Verhoef, (2002).

The aim of this paper is to highlight the importance of taking into account the interaction of all externalities in air transport markets when deciding the optimal environmental policy. We show that ignoring such interactions may lead to the choice of wrong environmental policies, reducing the social welfare of the overall economy. There are several papers in the literature looking for the optimal ranking of policies to tackle environmental damage in a general context (see Kolstad, 1999, for a general view) and, specifically, in the transport sector (see, for example, Calthrop and Proost, 2003, Fullerton and West, 2000, and Proost and Van Dender, 2001). However, in this paper we show that the optimal ranking of policies may strongly depend on whether regulators act or do not act in a myopic way, that is, on whether they ignore or not the consequences of each environmental policy on all externalities.

In particular, we consider a route in which there is only a carrier, who acts as a monopolist. This assumption is not unreal at all since in many airports some routes are operated just by one carrier. Moreover, as Brueckner (2002) points out, “though no carrier at any major airport controls 100% of the traffic, the monopoly case approximates the situation at many dominated hubs”. We assume that each operation produces an environmental damage that may be reduced through an abatement effort exerted by the carrier. The abatement effort is not costless, so it will not be implemented without public intervention. We focus on three possible public instruments to increase the carriers’ abatement effort: an emission tax, an emission subsidy and a technological standard. Even though all these regulatory policies may be equivalent in order to achieve the socially optimal level of noise or air pollution, they have different effects on the frequency to be offered. We assume that the transport infrastructure is not congested, so as the frequency increases the possibility to experience a reduction in passengers' travel time due to the schedule delay effect is always available.[2]

As it is usual in the literature, we assume that public funds are obtained through distortionary taxation. We also assume that emission taxes generate revenues that can be used to finance cuts in existing distortionary taxes. Indeed, some economists and politicians have argued that there might be a "double dividend" associated to the introduction of an emission tax, since an emission tax not only discourages environmentally damaging activities but it also reduces the distortion cost of the tax system (see, for example, Goulder, 1995, Goulder et al., 1997, Pearce, 1991, Poterba, 1993, or Repetto et al., 1992).

The rest of the paper is organized as follows. Section 2 presents the theoretical model. In section 3, we analyze as a benchmark situation the case in which there is no public intervention at all. For this case, we compare the private solution with the social optimum. In section 4, we discuss the optimal environmental policy and the importance of taking into account its effects on all externalities. Finally, in section 5 we conclude.

2. The model

We consider a route in which there is a single transport service provider with constant marginal operating cost denoted by c_0.[3] Let us denote by $G(Q)$ the consumers' generalized price, with Q being the total number of operations, that is, the frequency offered by the carrier. As Zhang and Zhang (2006) point out, this measurement of Q is equivalent to the number of passengers if each operation has an equal number of passengers, which holds when all vehicles are identical and have the same load factor.

[2] There are some other papers dealing with the trade-off between using a facility at a convenient time when the congestion is relatively high, or at a time when the facility is less congested but which is less convenient, implying higher schedule delay costs (see, for example, Kraus and Yoshida, 2002).

[3] The literature on costs functions for transportation is quite extensive. In particular, Oum and Waters (1997), find many examples of constant returns to scale for the air transport industry (7 out of 10 studies).

The inverse generalized demand function is assumed to be downward sloping, $G'(Q) < 0,$ and satisfies that $G''(Q)Q + 2G'(Q) < 0$ for every Q. This condition is clearly fulfilled if the inverse generalized demand function is either linear or convex, that is, $G''(Q) \leq 0.$

The consumers' generalized price is the sum of the ticket price P and the value of the time spent in making the trip $vT(Q)$, that is:

$$G(Q) = P + vT(Q), \tag{1}$$

where v is a positive parameter denoting the passengers' value of time (the same for everyone), and $T(Q)$ is the total time that a passenger spends in making the trip (including the access and egress time, the travel time and the schedule delay, that is, the gap between the actual and preferred departure time). We assume that the total amount of time required to make the trip decreases as the frequency increases, that is, $T'(Q) < 0.$ The higher the frequency, the lower the schedule delay, and thus the lower the consumers' generalized price.[4]

From expression (1) we can deduce the carrier's perceived inverse demand function, which relates the quantity demanded and the ticket price:

$$P(Q) = G(Q) - vT(Q). \tag{2}$$

When operating, the air transport service provider produces pollutant emissions, such as noise and air pollution. We assume that each operation causes a constant environmental damage denoted by $d \in (0,1).$ However, the operator may reduce the amount of his emissions of noise and air pollution through an abatement effort. The abatement effort can take different forms, such as the use of cleaner technology or cleaner fuels, operating at lower speed, etc. Let us denote by $e \in [0,1]$ firm's abatement effort per operation, which is supplied at a constant marginal cost c_e per operation. We assume that both the cost of effort and the marginal cost of effort are zero if no effort is exerted, that is, $c_e(e = 0) = 0$

[4] Recall that we assume that the airport is not congested. In a congested airport, the higher the frequency, the lower the schedule delay but the higher the congestion cost. Thus, if the frequency increases the consumers' generalized price may decrease (if the schedule delay effect dominates) or it may increase (if the congestion cost effect dominates).

and $\frac{dc_e}{de}(e=0)=0.$ We also assume that the marginal cost of effort is one if the maximum effort is exerted, that is, $\frac{dc_e}{de}(e=1)=1.$ Finally, the marginal cost of effort is assumed to be an increasing and convex function of $e.$ By construction, $(1-e)\in[0,1]$ denotes firm's final level of emissions per operation. We assume that if the transport service provider exerts an abatement effort e, then the environmental damage reduces to $d(1-e)$.

From the previous assumptions, we can deduce that the total cost $C(Q)$ for the transport operator is a linear function of the total number of operations. Formally:

$$C(Q)=c_T Q=(c_o+c_e)Q, \qquad (3)$$

where c_T denotes the total marginal cost for the air transport service provider, obtained as the sum of the marginal operating cost and the cost of effort (both constant per operation).

3. Benchmark case: no environmental regulation

Let us compare the carrier's profit-maximizing choice of abatement effort and frequency with the socially optimal solutions.

3.1. The carrier's optimum

The carrier chooses the level of frequency and abatement effort in order to maximize its own profit. The carrier's profit $\pi(Q,e)$ is the difference between total revenues and total costs. The carrier's total revenue function is derived from the carrier's perceived inverse demand function, that is, the one relating the quantity demanded and the ticket price. Formally:

$$\underset{Q,e}{Max}\ [G(Q)\text{-}vT(Q)]\,Q\ \text{-}\ c_T Q. \qquad (4)$$

If the government does not intervene at all, the carrier chooses the level of abatement effort that minimizes his total costs. Clearly, the operator's total costs are minimized by setting $e^{NI}=0,$ where the superscript NI denotes the case in which there is no public intervention.

To determine the profit-maximizing service frequency, the carrier solves the maximization programme given by expression (4). Thus, the choice of frequency is obtained by setting the first derivative of profits, $\pi(Q,e)$, with respect to Q equal to zero. Using subscripts to denote profits partial derivatives, the first order condition of such a maximization program can be written as:

$$\pi_Q(Q^{NI},e^{NI}) = G'(Q^{NI})Q^{NI} - vT'(Q^{NI})Q^{NI} + G(Q^{NI}) - vT(Q^{NI}) - c_T = 0. \qquad (5)$$

The second order condition of the operator's maximization problem is given by:

$$\pi_{QQ}(Q^{NI},e^{NI}) = G''(Q^{NI})Q^{NI} + 2G'(Q^{NI}) - v[2T'(Q^{NI}) + Q^{NI}T''(Q^{NI})] < 0, \qquad (6)$$

which we assume it is satisfied. Thus, expression (5) implicitly defines the optimal frequency to be offered by the transport service provider without public intervention.

Condition (5) just implies that the carrier's marginal revenue function (MR) equals the marginal cost. Condition (6) requires the marginal revenue to cut the marginal cost from above but, since the marginal cost c_T is constant, expression (6) reduces to the condition that the marginal revenue function is downward sloping.

3.2. The social optimum

Social welfare is defined as the sum of consumer surplus and the carrier's profits, minus the external cost of the noise or environmental pollution.[5] If the regulator were able to control directly the choice of abatement effort and frequency, he would solve the following maximization program:

$$\underset{Q,e}{Max}\ SW(Q,e) = [\int_0^Q G(z)dz - G(Q)Q] + [G(Q) - vT(Q) - c_o - c_e(e)]Q - d(1-e)Q. \quad (7)$$

First order conditions lead to the following expressions:[6]

[5] Notice that consumers pay a generalized price $G(Q) = P + vT(Q)$. However, the carrier only charges the ticket price P. The total value of time $vT(Q)Q$ is a cost for the consumers but it is not a revenue for the carrier, so the social benefit is the area under the generalized demand curve up to Q minus $vT(Q)Q$.

[6] Second order conditions are assumed to be satisfied.

$$\frac{dc_e}{de}(e^{SO}) = d. \tag{8}$$

$$\pi_Q(Q^{SO}, e^{SO}) - G'(Q^{SO})Q^{SO} - d(1 - e^{SO}) = 0, \tag{9}$$

where superscript SO denotes the socially optimal solution. The investment in noise or air pollution abatement effort is optimal when the marginal cost of abatement per operation equals the marginal benefit of abatement effort per operation, d. Hence, it is socially optimal to force the operator to exert a strictly positive effort in reducing noise and air pollution, though it is not socially optimal to force him to exert the maximum effort.

Let us define the (positive) demand elasticity with respect to the generalized price as $\varepsilon \equiv -\frac{dQ}{dG}\frac{G}{Q} = -\frac{G}{G'Q}$. If the demand elasticity evaluated in the socially optimal frequency $\varepsilon(Q^{SO})$ is low (high) enough, for every possible abatement effort, the optimal frequency from the social point of view will be higher (lower) than the frequency offered by the carrier. Thus, if $\varepsilon(Q^{SO})$ is low (high) enough, it is socially optimal to increase (decrease) the frequency, since the social loss in terms of consumer surplus would be higher (lower) than the total environmental damage. All these results are summarized in the following Lemma.

Lemma 1: *The socially optimal level of abatement effort per operation is higher than the effort exerted by the carrier without public intervention. Moreover, if* $\varepsilon(Q^{SO})$ *is low (high) enough, for every abatement effort, the socially optimal frequency is higher (lower) than the frequency offered by the operator.*

Proof: The proof proceeds in two steps. The first step consists of proving that $e^{SO} > 0.$ We know that the marginal cost of effort is an increasing function of $e,$ and $\frac{dc_e}{de}(e = 0) = 0.$ Moreover, we know that $d \in (0,1).$ Thus, from condition (8) we can conclude that $e^{SO} > 0,$ as we wanted to prove. The second step consists of proving that if $\varepsilon(Q^{SO})$ is sufficiently low, for every $e,$ $Q^{SO} > Q.$ Consider the following generalized maximization problem:

$$\underset{Q,e}{Max}\ Z(Q,e,\theta)=\theta[\int_0^Q G(z)dz - G(Q)Q]+\ [G(Q)-vT(Q)-c_o-c_e(e)]Q\ -\ \theta d(1-e)Q,$$

which reduces to the social welfare optimization problem when $\theta=1$, and the profit-maximization problem when $\theta=0$. First order conditions with respect to e and Q for this generalized maximization problem are, respectively, given by:

$$-\frac{dc_e}{de}(e)Q+\theta dQ=0.$$

$$-\theta[G'(Q)Q+d(1-e)]+[G'(Q)-vT'(Q)]Q+G(Q)-vT(Q)-c_o-c_e(e)=0.$$

Let us now investigate the sign of $dQ/d\theta$. Applying the implicit function theorem we have that:

$$\begin{bmatrix}\dfrac{de}{d\theta}\\ \dfrac{dQ}{d\theta}\end{bmatrix}=\begin{bmatrix}-\dfrac{d^2c_e}{de^2} & 0\\ 0 & -\theta[G''(Q)Q+G'(Q)]+[G''(Q)-vT''(Q)]Q+2G'(Q)-2vT''(Q)\end{bmatrix}^{-1}\begin{bmatrix}-dQ\\ G'(Q)Q+d(1-e)\end{bmatrix},$$

where the second term is the inverse of the Hessian matrix. Then:

$$\frac{dQ}{d\theta}=\frac{G'(Q)Q+d(1-e)}{-\theta[G''(Q)Q+G'(Q)]+[G''(Q)-vT''(Q)]Q+2G'(Q)-2vT''(Q)}.$$

The denominator is negative by definition (the Hessian matrix is assumed to be negative definite for the second order condition to be satisfied), so if $-G'(Q)Q>(<)\ d(1-e)$, which holds when $\varepsilon(Q)<(>)\dfrac{G(Q)}{d(1-e)}$, that is, when $\varepsilon(Q)$ is low (high) enough, $dQ/d\theta$ is positive (negative), and thus the socially optimal frequency is higher (lower) than the frequency offered by the operator. This completes the proof.■

The operator sets the marginal revenue equal to his marginal private cost. The regulator sets the marginal social benefit equal to the marginal social cost. The marginal social benefit curve lies above the marginal revenue curve, and the marginal social cost curve lies above the operator’s marginal cost curve. If the demand is perfectly elastic, the marginal social benefit and the marginal revenue curves coincide, and so the socially optimal frequency is lower than the frequency offered by the operator.

From this case we can obtain some interesting results. On the one hand, forcing the carrier provider to exert a strictly positive abatement effort may have a negative effect on the frequency to be offered. Such a negative impact on the frequency due to an increase in firm's abatement effort will be intensified (mitigated) if a schedule delay effect exists and the marginal social travel time is decreasing (increasing) in the frequency. The schedule delay exists when the consumers' travel time decreases as the frequency increases, $T'(Q) < 0$. On the contrary, there is no schedule delay when the consumer's travel time is independent from the frequency, $T'(Q) = 0$. The total social travel time is denoted by $QT(Q)$, and the marginal social travel time is given by $T(Q) + QT'(Q)$. If there is a schedule delay, the operator internalizes it in his perceived demand function and offers a higher frequency.[7] However, an increase in the carrier's total marginal cost implies a reduction in the frequency. If the marginal social travel time is decreasing (increasing) in the frequency, the monopoly will (not) be able to decrease the frequency without losing too much revenue. In such a case, the reduction of the frequency will be exacerbated (mitigated). These results are formally stated in the following proposition:

Proposition 1: *If the operator is forced to exert a strictly positive abatement effort, the profit-maximizing frequency offered would be reduced. However, such a reduction would be higher (lower) if there is a schedule delay and the marginal social travel time is decreasing (increasing) in* Q*.*

Proof: On the one hand, if the carrier were forced to exert a strictly positive effort, his total marginal cost c_T would be increased. Applying the implicit function theorem to the first order condition given by expression (5), it is straight forward to prove that as c_T rises, the optimal frequency Q decreases. Formally:

$$dQ / dc_T = 1 / \pi_{QQ} < 0,$$

[7] In our model, the operator is a monopolist so he fully internalizes the schedule delay effect. In a Cournot oligopoly, the schedule delay effect is only partly internalized, since each carrier considers only the schedule delay effect of its own passengers.

where $\pi_{QQ} = G''(Q)Q + 2G'(Q) - v[2T'(Q) + QT''(Q)]$, if there is a schedule delay, and $\pi_{QQ} = G''(Q)Q + 2G'(Q)$, otherwise.

The condition $2T'(Q) + QT''(Q) < 0$, just implies that the marginal social travel time is decreasing in Q. Thus, if the marginal social travel time is decreasing (increasing) in Q, the reduction of the frequency due to an increase in firm's abatement effort would be higher (lower) if there is a schedule delay. This completes the proof. ■

The abatement effort is not costless so the transport operator will exert no effort without public intervention. Thus, in this context the government's intervention is justified.

From Proposition 1 we can deduce that a policy aimed to increase the operator's abatement effort may have a negative impact on the frequency to be offered. However, such a negative effect will be mitigated (exacerbated) if there is a schedule delay and the marginal social travel time is increasing (decreasing) in the frequency. The intuition of this result is as follows: if the total amount of time required to make the trip decreases with the frequency, the consumers' generalized price will increase as the frequency decreases. So, the lower the frequency, the lower the ticket price that the carrier can charge to passengers. Therefore, when deciding the frequency to be offered, the carrier takes into account the negative effects that reductions in the frequency has on travel times. Besides, if the marginal social travel time is increasing (decreasing) in Q, passengers (and thus the carrier's revenues) will be even more (less) sensitive to reductions in frequency. Thus, the carrier will optimally choose to mitigate (increase) the reduction in the frequency.

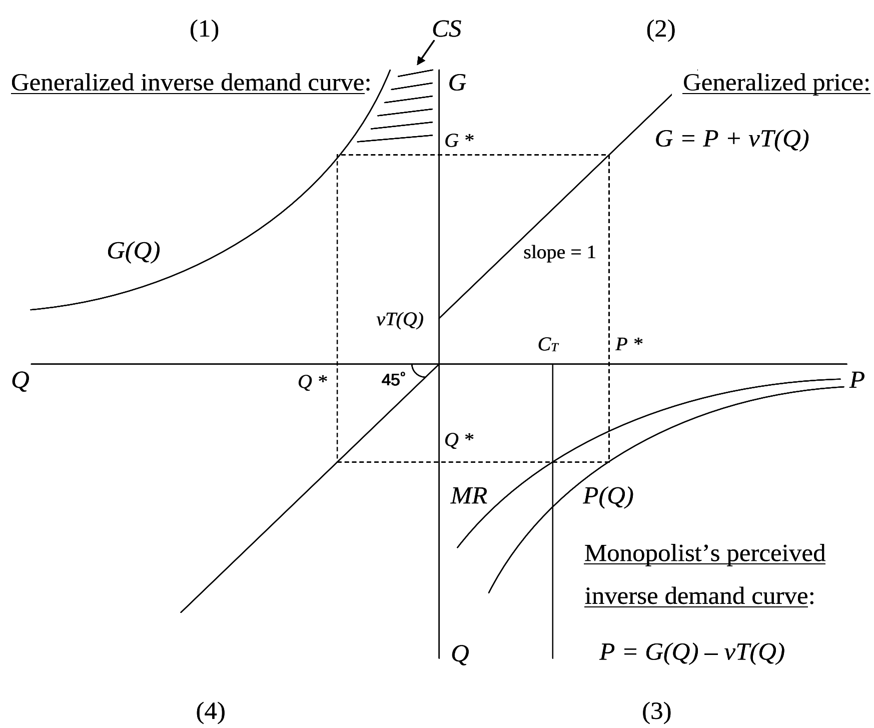
The choice of the profit-maximizing frequency by the carrier and its effects in social terms are depicted in the four-quadrant diagram of Figure 1. The first quadrant displays the generalized inverse demand curve, relating the quantity demanded to the generalized price. The second quadrant relates the generalized price paid by passengers G, and the ticket price charged by the carrier P. The third quadrant displays the carrier's perceived inverse demand curve relating P to Q. Finally, the fourth quadrant just displays the 45-degree line.

The carrier’s choice of Q is obtained in the third quadrant in the usual way, as the level of Q that equates marginal revenue to private marginal cost. Then, having determined the level of Q, social surplus can be calculated in the first quadrant. Notice that the schedule delay causes the carrier’s perceived demand curve to become more elastic. However, when there is a schedule delay the slope of the carrier’s marginal revenue function is given by:

$$\frac{dMR}{dQ} = G''(Q)Q + 2G'(Q) - v\,[2T'(Q) + QT''(Q)]. \tag{10}$$

Thus, when there is a schedule delay and the marginal social travel time is decreasing (increasing) in Q, $2T'(Q) + QT''(Q) < (>) 0$, the carrier’s marginal revenue function becomes flatter (steeper). That is why the reduction in the frequency due to an increase in total marginal cost c_T is higher (lower) when there is a schedule delay and the marginal social travel time is decreasing (increasing) in Q.

Figure 1: Four-quadrant diagram: (1) Generalized inverse demand curve, (2) Generalized price, (3) Carrier’s perceived inverse demand curve, (4) The 45-degree line.



The government can make use of several instruments to increase the carrier's abatement effort, such as emission taxes, emission subsidies or technological standards. All these instruments induce different effects on the number of operations to be offered and the overall distortions of the economy. Moreover, as shown in Proposition 1, the effect of a certain environmental policy on the frequency to be offered will strongly depend on the existence of the schedule delay.

In the next section we show that, when there is a schedule delay, the optimal ranking of policies may strongly depend on whether regulators act or do not act in a myopic way. The reason is that, when there is a schedule delay, the operator internalizes such an effect in its perceived demand function. If the regulator does not take into account this positive externality, he will fail in predicting the effects of the different environmental policies and he may end up choosing the wrong one.

4. Optimal environmental policy

We assume that the regulator has committed to implement the social optimal level of noise or air pollution. Given this commitment, he has to look for the optimal environmental policy to implement the socially optimal level of abatement effort.[8] The socially optimal level of noise or air pollution can be achieved either by an emission tax, an emission subsidy or a technological standard. Although these policies may be equivalent to achieving such an optimal level of noise or air pollution, they have different effects on the frequency to be offered by the carrier, and thus on the social welfare. Moreover, emission taxes generate revenues that can be used to finance cuts in existing distortionary taxes. Let us analyze the optimal environmental policy to be implemented in this context.

In Section 3, we show that the socially optimal level of abatement effort e^{SO} satisfies that $\frac{dc_e}{de}(e^{SO}) = d$. In this section, we will analyze three alternative policies to implement such an abatement effort. The first one is an emission tax. Let t be the emission tax that the operator must pay per operation, which is proportional to his emission rate. The operator

[8] This commitment may be due to an international agreement about the level of pollution and/or noise.

chooses the level of abatement effort in order to minimize his total costs. Thus, when deciding his abatement effort, the carrier must balance the additional cost of exerting more effort against the reduction in tax payments. Formally, the operator chooses the level of effort that solves the following minimization problem:

$$\underset{e}{Min}\ t(1-e)+c_e. \tag{11}$$

The first order condition requires that $\frac{dc_e}{de}(e^{ET})=t,$ where the superscript ET denotes the presence of an emission tax. Clearly, by setting $t=d$, the government implements the socially optimal effort. In this case, the carrier's total marginal cost is given by the following formula:

$$c_T^{ET}=c_o+d(1-e^{SO})+c_e(e^{SO}). \tag{12}$$

The second policy that might be used by the regulator to implement the socially optimal level of abatement effort is an emission subsidy. Let s be the emission subsidy per operation that the transport service provider obtains for each unit of abatement effort. In this case, when deciding the level of abatement effort to be exerted, the operator solves:

$$\underset{e}{Min}\ c_e-se. \tag{13}$$

The optimal solution implies that $\frac{dc_e}{de}(e^{ES})=s,$ where the superscript ES denotes the existence of an emission subsidy. By setting $s=d$, the government implements the socially optimal effort, and the operator's total marginal cost is given by:

$$c_T^{ES}=c_o+c_e(e^{SO})-de^{SO}. \tag{14}$$

Finally, the third policy that may be used by the government to implement the socially optimal level of abatement effort is a command and control policy. Command and control regulations applied to transport typically imply the introduction of some requirements or standards on the vehicles and the technology to be used. Suppose that the regulator issues detailed requirements for the operator in order to force him to exert an effort e^{SO}. Using the superscript TS to denote the presence of a technological standard, the carrier's total marginal cost is given by the following expression:

$$c_T^{TS} = c_o + c_e(e^{so}). \tag{15}$$

Although the socially optimal level of abatement effort can be achieved either with an emission tax, an emission subsidy or a technological standard, all these policies have different effects on the carrier's total marginal cost and, thus, on the frequency to be offered. Indeed, comparing expressions (12), (14) and (15), it is straight forward to see that $c_T^{ES} < c_T^{TS} < c_T^{ET}$ and, thus, $Q^{ES} > Q^{TS} > Q^{ET}$. These results are summarized in the following lemma.

Lemma 2: *The socially optimal level of abatement effort can be implemented either with an emission tax, an emission subsidy or a technological standard. However, all these policies have different effects on the frequency offered by the carrier. In particular, an emission subsidy induces the highest frequency while an emission tax, the lowest.*

Proof: The optimal frequency offered by the operator is given by setting $\pi_Q(Q, e^{SO}) = 0.$ The optimal frequency Q is implicitly defined by such a first derivative and, applying the implicit function theorem, we have that $dQ/dc_T = 1/\pi_{QQ} < 0.$ Since $c_T^{ES} < c_T^{TS} < c_T^{ET}$, then $Q^{ES} > Q^{TS} > Q^{ET}$, as we wanted to prove. ■

With an emission subsidy the regulator manages to implement the socially optimal level of abatement effort and the highest frequency. But any subsidy requires the use of public funds that are obtained through distortionary taxation. Let λ denote the cost of public funds.

The social welfare if an emission subsidy is used to implement the socially optimal level of abatement effort e^{SO} is given by the following formula:

$$SW(Q^{ES}, e^{SO}) = [\int_0^{Q^{ES}} G(z)dz - G(Q^{ES})Q^{ES}] + [G(Q^{ES}) - vT(Q^{ES}) - c_o - c_e(e^{SO}) + de^{SO}]Q^{ES}$$
$$- d(1 - e^{SO})Q^{ES} - (1+\lambda)de^{SO}Q^{ES}. \tag{16}$$

The socially optimal level of abatement effort may be also implemented through an emission tax, though this policy induces the lowest frequency. If we assume that the revenues that are obtained through such a tax are used to reduce the overall distortions of the economy, the social welfare is obtained by:

$$SW(Q^{ET}, e^{SO}) = [\int_0^{Q^{ET}} G(z)dz - G(Q^{ET})Q^{ET}] + [G(Q^{ET}) - vT(Q^{ET}) - c_o - d(1 - e^{SO}) + c_e(e^{SO})]Q^{ET}$$
$$- d(1 - e^{SO})Q^{ET} + (1+\lambda)d(1 - e^{SO})Q^{ET}. \tag{17}$$

Command and control policies can be implemented without affecting the government's revenues since they only imply the fulfilment of certain requirements. Thus, if a technological standard is used to implement the socially optimal level of abatement effort, the social welfare is given by the following expression:

$$SW(Q^{TS}, e^{SO}) = [\int_0^{Q^{TS}} G(z)dz - G(Q^{TS})Q^{TS}] + [G(Q^{TS}) - vT(Q^{TS}) - c_o - c_e(e^{SO})]Q^{TS}$$
$$- d(1 - e^{SO})Q^{TS} . \tag{18}$$

From Lemma 1 we know that, if the demand elasticity evaluated in the socially optimal frequency $\varepsilon(Q^{SO})$ is low enough, for every possible abatement effort, the frequency offered by the operator is lower than the optimal frequency from a social point of view. Thus, if $\varepsilon(Q^{SO})$ is low enough, when deciding the optimal environmental policy to implement the socially optimal level of abatement effort, the regulator faces a trade off. On the one hand, the highest (lowest) frequency is obtained with an emission subsidy (tax). On the other hand, the use of subsidies increases (decreases) the overall distortion of the economy.

In this section we show that, when there is a schedule delay, the optimal ranking of policies may strongly depend on whether regulators act or do not act in a myopic way. Regulators act in a myopic way when they do not take into account the effects that a particular policy has on other air transport externalities such as the schedule delay. The carrier does internalize the schedule delay in its perceived demand function, so if the regulator does not take into account such a positive externality, he will fail in predicting the real effects of the different environmental policies.

For example, suppose that there is a schedule delay but the regulator does not take it into account, and he chooses an emission tax rather than an emission subsidy. If the regulator chooses such a policy it is because the negative impact of taxes on the frequency is lower than the positive impact of taxes in terms of the overall distortions on the economy. However, we know that the effect of the environmental policies on the frequency is higher if there is a schedule delay and the marginal social travel time is decreasing in Q. So in this case, if the regulator would have considered the effects of the environmental policy on the schedule delay, the optimal ranking of policies might have been different. A similar result may be obtained when there is a schedule delay and the marginal social travel time is increasing in Q. This is stated in the following proposition.

Proposition 2: *If there is a schedule delay, the optimal ranking of policies may depend on whether regulators act or do not act in a myopic way, that is, on whether they take into account the effects that each environmental policy has on just environmental externalities or on all air transport externalities.*

Proof: To demonstrate that this possibility may indeed arise, let us consider the following counter example: Suppose a linear inverse generalized demand function, that is, $G = \alpha - \beta Q,$ and quadratic costs for effort, $c_e = e^2 / 2.$ This latter assumption implies that the marginal cost of abatement is rising, that is, more sophisticated and costly techniques are required to further decrease pollutant emissions.[9]

Assume that the total amount of time required to make the trip is given by $T(Q) = a + (f / \sqrt{Q})$, where a denotes the minimum time (in hours) required to make the trip. As Q increases, the total amount of time $T(Q)$ tends to the minimum a. This is the so-called schedule delay. Notice that in this case $2T'(Q) + QT''(Q) < 0$, that is, the marginal social travel time is decreasing in Q.[10] The square root specification has been obtained from structural models (see Mohring ,1972) and it has been extensively used in empirical papers (see, for example, Borenstein and Netz, 1999, or Richard, 2003).

The carrier internalizes the schedule delay in its perceived demand function and he chooses the optimal frequency. However, we assume that the regulator acts in a myopic way, that is, he considers just one kind of externality at the time. In particular, he considers the environmental externalities (noise and air pollution) but he ignores the existence of a positive externality: the schedule delay. In other words, the regulator considers that the total amount of time required to make the trip is given by: $T = a + b$, where b denotes the distance between the real total time and the minimum. Such a distance is strictly positive and does not depend on the frequency.

In order to search for the optimal environmental policy, the regulator tries to anticipate the effects of different environmental policies on the abatement effort and frequency offered by the carrier. However, when the regulator ignores the schedule delay, he fails in predicting the real effects of the different environmental policies.

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[9] The assumption of quadratic costs for abatement effort is usually applied in the environmental economics literature. Some examples are Calthrop and Proost (2003), Chavez and Stanlund (2003), Hoel and Karp (2001), Nannerup (1998), and Yates and Cronshaw (2001).

[10] A similar result can be obtained for the case in which the marginal social travel time is increasing in the frequency. An example of a function satisfying that $2T'(Q) + QT''(Q) > 0$ is $T(Q) = a + f / Q^2$.

Suppose the following values for the parameters: $\alpha = 75,$ $\beta = 1,$ $v = 6,$ $a = 10,$ $b = 1.55,$ $c_o = 5,$ $d = 0.5,$ $f = 2$ and $\lambda = 0.4.$ [11] In other words, we are assuming a linear and unitary slope inverse generalized demand function for a long-distance trip (minimum 10 hours). The value of time is 6 euros per hour, which is consistent with the values estimated in the *HEATCO Project* that ranges from 4.09 to 22.82, depending on the transport mode and the country (see Bickel et al., 2006).[12] The value for the distortion cost is also consistent with the empirical evidence, ranging from 0.15 to 0.5,[13] and the value for the environmental damage is assumed to be intermediate.

The following table compares the social welfare and the frequency predicted by the regulator if an emission subsidy, a technological standard or an emission tax is used to implement the socially optimal level of abatement effort, $e^{SO} = 0.5,$ in both cases, when the regulator acts in a myopic way and when he considers all the externalities. It also includes the frequency and the social welfare obtained if there is no public intervention and the operator exerts no effort at all.

[11] This is just a counter example to prove Proposition 2. Obviously, different value of parameters may lead to different results.

[12] The estimated values are for long-distance non-work passenger trips. Higher values of time correspond to richer countries and/or the air transport industry. Thus, the lowest value of 4.02 corresponds to bus trips in Lithuania and the highest value of 22.82 corresponds to air transport in Luxembourg.

[13] There are several papers in the literature estimating the cost of public funds. For instance, Ballard et al. (1985) find that the welfare loss due to 1% increase in all distortionary tax rates is between 17% and 56% per dollar. More generally, it seems that the shadow cost of public funds lies in the range of 15% to 50% in countries with a developed efficient tax-collection system (Gagnepain e Ivaldi, 2002).

Table 1: Comparison of environmental policies for the cases in which either the regulator acts in a myopic way or he considers all the externalities, and $T(Q) = a + f / \sqrt{Q}$

	The myopic solution				All externalities are considered			
	e	***Q***	***SW***	Δ***SW***	***e***	***Q***	***SW***	Δ***SW***
Emission subsidy	0.5	0.4125	0.0077	-11.49%	0.5	3.4465	4.611	7.44%
Technological standard	0.5	0.2875	0.0521	498.85%	0.5	3.2814	4.4621	3.97%
Emission tax	0.5	0.1625	0.0558	541.37%	0.5	3.1119	4.2526	-0.90%
No intervention	0	0.35	0.0087	-	0	3.3644	4.2914	-

The increase in social welfare due to the introduction of a certain environmental policy varies depending on whether the regulator acts or does not act in a myopic way. In particular, if the regulator does not take into account the schedule delay, he would fail in predicting the frequency to be offered by the carrier. Taking into account these wrong predictions, the regulator would choose firstly, an emission tax, and secondly, a technological standard. An emission subsidy would never be chosen by the regulator, since the social welfare when such a policy is used is lower than when there is no public intervention at all. However, if the regulator considers all externalities the optimal ranking of environmental policies would be completely different. In this case, he would correctly predict the frequency to be offered by the carrier and he would choose firstly, an emission subsidy, and secondly, a technological standard. In this example, if the regulator acts in a myopic way and focuses just on environmental externalities, he may end up choosing an emission tax, which is the worst policy to be used (even worst than when there is no public intervention). Moreover, given his wrong predictions, the regulator will never choose an emission subsidy, which is the best policy to be implemented in this example.

The higher the schedule delay, the larger the differences between what the regulator predicts and what really happens and, hence, the losses in terms of social welfare. Moreover, if we compare the frequency and level of social welfare for the cases in which the schedule delay is and is not considered, we can observe that both are higher in the former case.

This completes the proof. ■

5. Conclusions

Although most externalities found in air transport have a negative impact, there may also be a positive effect: the so-called impact on the “schedule delay”. Passengers have a preferred departure time and dislike the “schedule delay”, which is equal to the difference between the actual and preferred departure time. Increases in frequency reduce the “schedule delay” and, hence, consumers’ generalized price.

The existence of such a positive externality may have important consequences on the optimality of environmental policies. However, environmental regulators do not usually take into account the positive impact that the frequency has on the consumers’ generalized price. The model analyzed in this paper highlights the importance of considering this positive externality when choosing the optimal environmental policy in air transport. In particular, we show that if there is a schedule delay, the impact of environmental policies on the frequency to be offered might be either exacerbated or mitigated. As a consequence, if this positive effect is not taken into account by the regulator, the environmental policy chosen may not be optimal.

Although for the sake of simplicity in this paper we consider a carrier that operates as a monopolist in a non-congested airport, the main result of the paper would stand even if we assume the opposite: the optimal ranking of policies may strongly depend on whether regulators act or do not act in a myopic way, that is on whether they take or do not take into account the effects that a particular environmental policy has on other air transport externalities, such as the schedule delay or the level of congestion.

All the results obtained in this paper can be extended to other transport modes in which the route is operated by a monopolist. For air, maritime and rail transport, when a passenger decides to make a trip, he knows in advance all relevant details, such as departure and arrival scheduled times and thus, increases in frequency reduce the schedule delay. For other transport modes, such us the bus industry, in which vehicles arrive randomly to the stops, increases in frequency reduces the time that passengers have to wait at the stop till the vehicle finally comes. In this latter case, the positive externality is the so-called Mohring effect due to Mohring (1972). Either the impact on the schedule delay or the Mohring effect should be taken into account by environmental regulators when looking for the optimal environmental policy.

General results of the environmental economics literature cannot be directly applied to the transport sector since there are specific effects in transport, such as the impact on the schedule delay (or the Morhing effect) and the level of congestion, that are not present in other sectors or industries in the economy. Disregarding the importance of such specific effects in the air transport sector may lead to the choice of wrong environmental policies, reducing the social welfare of the overall economy.

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