How to Mix Per-flight and Per-passenger Based Airport Charges

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March 28, 2014

Abstract

This study compares the optimal mix of per-flight and per-passenger based airport charges from the monopoly carriers’ and the social viewpoints conditional on airport cost recovery. Specifically, it concentrates on the trade-off between price and frequency (i.e., schedule delays) when time valuations are uniform or differ between business and leisure passengers. We identify an easy test for the evaluation of the mix of per-passenger and per-flight based airport charges by policy makers, which is simply to check whether the carrier’s preferred per-flight charge is zero.

Keywords: Airport; per-passenger charge; per-flight charge; schedule delays; time valuations.

JEL: D21; H20; H40; L93; R48.

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*We thank Robin Lindsey, Tae Oum and seminar participants at the Centre for Transportation Studies Seminar (University of British Columbia) for helpful comments and suggestions. Partial financial support from the Social Science and Humanities Research Council of Canada (SSHRC) is gratefully acknowledged.

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1 Introduction

“Many airport facilities are built and maintained for the benefit of airline passengers. It is in the interest of both the airport and the airlines to recover these costs through passenger based charges instead of other aeronautical based charges.” (International Air Transport Association, IATA, July 2010)

Traditionally, aeronautical charges are based on aircraft weight formula, which is especially true for landing, parking and hangar charges. But, as airport improvement fees, which are used to charge passengers for airport infrastructure development and/or debt repayment, have become a more important revenue source for airports (Zhang, 2012), airports worldwide derive today as much aeronautical revenues from per-passenger charges as from aircraft related (i.e., per-flight) charges (ACI, 2008). Yet, the trade association for the world’s airlines (International Air Transport Association, IATA) seems to propose to further move away from per-flight related airport charges towards per-passenger related charges.

Why are carriers interested in raising per-passenger airport charges relative to per-flight charges? Is the carriers’ proposal socially optimal? In this paper we investigate these questions. The issues are addressed by comparing a monopoly carrier’s and the social viewpoints on the optimal mix of airport-charges conditional on strict airport-cost recovery through revenues derived from airport per-flight and per-passenger charges. A crucial element of the model is that passengers experience schedule delays, which measure the absolute difference between the passengers’ most preferred and their actual travel times. Following Douglas and Miller (1974) and more recent work by, e.g., Bilotkach (2007), Brueckner (2004 and 2010) and Brueckner and Flores-Fillol (2007), it is assumed that schedule delays are negatively related to the quantity of aircraft flights, i.e. frequency, because an increase in frequency increases the likelihood that passengers travel at their preferred times. Schedule delay costs then depend on frequency and

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1The International Civil Aviation Organisation (ICAO) proposes that landing charges as well as parking and hangar charges should be based on aircraft weight formula (ICAO, 2012).
time valuations. In this scenario, passenger demands depend on “full fares,” which are composed of ticket price and schedule delay costs. The model therefore establishes a clear trade-off between low per-passenger charge, low price, and low frequency versus low per-flight charge, high price and high frequency.

Our analysis shows that an increase in the per-passenger airport charge and the associated reduction in the per-flight charge can indeed increase carrier profit. Essentially, the reduction in schedule delay costs associated with a marginal increase in frequency, which is fully internalized by the carrier when the passengers’ time valuations are uniform, exceeds the marginal frequency cost when the per-flight charge is positive. The picture becomes more complex when passengers with distinct time valuations exist. There is good evidence that business passengers exert high time valuations relative to leisure passengers (e.g. Morrison, 1987; Morrison and Winston, 1989; US-DOT, 1997; Pels et al., 2003). Then, if the carrier charges a uniform price to business and leisure passengers, exact internalization of reductions in schedule delays is not ensured. Specifically, if the average time valuations (defined as the arithmetic mean of all passengers’ time valuations) exceeds the marginal passengers’ time valuations (defined as the average time valuation of incremental passengers), the carrier’s incentive to provide frequency is too low because it is concerned with the marginal time valuations. This translates into a preference for low per-passenger charge and high per-flight charge relative to a carrier that would be concerned about the average time valuations. The distinction between the marginal and average time valuations becomes however less relevant when a carrier can price discriminate between business and leisure passengers in the form of third-degree price discrimination by, for example, advanced purchase rebates.²

Turning to the social maximizer, she is concerned not only about producer surplus

²Airlines are a frequently used example for markets where price discrimination is prevalent (for example, Borenstein 1985, Dana 1999a/1999b and Cowan 2007). Stavins (2001) and Lazarev (2013) provide empirical evidence for airline third-degree price discrimination. To abstract away from self-selection, assume that early booking is prohibitive for business passengers.
but also about consumer surplus, and adding the consumers’ viewpoint into consider-
ation means minimization of full fares conditional on airport cost recovery. Thus,
the carrier’s and social viewpoints can be identical only if the carrier’s preferred mix
of airport charges minimizes full fares. While policy makers may have difficulties to
identify the minimization of full fares, we further show that the carrier’s and the social
viewpoints are identical only if the carrier’s preferred per-flight charge is exactly equal
to zero when time valuations are uniform. Furthermore, the zero per-flight charge can
still be optimal from the carrier’s and the social viewpoints if time valuations differ
between passenger groups, but only if ticket prices are discriminating. These results
thus suggest an easy test for the potential conflicts of interest between the carrier and
the social maximizer, which is to simply check whether the carrier’s optimal mix of
airport charges incorporates the zero per-flight charge. Numerical tests further indicate
that the carrier’s per-passenger charges are more likely to be excessive from the social
viewpoint if time valuations are high.

Our paper contributes to several strands of the literature. The first is to the lit-
erature on airport pricing, which typically concentrates on congestion pricing and the
pricing of airport concession services based on passenger related charges. For exam-
ple, Flores-Fillol (2010) analyzes airport congestion pricing when schedule delays are
present but concentrates on per-passenger related charges. Silva and Verhoef (2013)
consider a congested airport and per-flight and per-passenger charges. They find that
market power should be corrected by the per-passenger subsidy and that the per-flight
charge should be used to control congestion. To our knowledge, our paper is the first
that evaluates the mix of airport per-passenger and airport per-flight charges from the
carrier’s and the social viewpoints. Note that similar issues may also arise in other
transportation infrastructures. In the port sector, for example, port charges may be
levied on the ship and cargo. More specifically, prices charged for servicing a container-
ship and its cargo at a port may include: i) (charged to the vessel) prices for pilotage,

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3See Zhang and Czerny (2012) for a survey paper on airport congestion pricing and airport conces-
sion revenues.
tuggage, dockage, line-handling, and vessel overtime; and ii) (charged to container box)
prices for wharfage, stevedoring, rental of terminal cranes, and number of containers
moved on to and off the vessel. Furthermore, there have been discussions about the
optimal pricing structures from the perspectives of shipping lines, the port, shippers
(i.e., cargo owners) and welfare (e.g., Tally, 2009). The insights derived in the present
paper may therefore be relevant for port policies and, thus, adds to the sea port litera-
ture. Since schedule delays can be considered as a quality dimension, this paper further
adds to the literature on quality supplies, which was introduced by the seminal papers
of Spence (1975) and Sheshinski (1976).

This paper is organized as follows. Section 2 develops the basic model, which is used
to derive the price and frequency effects of a marginal increase in per-passenger charges
under fixed frequency and endogenous frequency, respectively, in Section 3. Price and
frequency effects are crucial for the evaluation of the mix of airport charges from the
carrier’s and the social viewpoints. This section also provides an example, which makes
use of specific functional forms and numerical parameter instances to illustrate the
distinct viewpoints on the mix of airport charges. Passenger types with distinct time
valuations are considered in Section 4, which also includes an example to illustrate
the effect of uniform prices versus price discrimination on the optimal mix of airport
charges. Section 5 concludes and provides avenues for future research.

2 Basic Model

The supply side is described first. There is an upstream airport that provides an
essential input (e.g., runway and terminal capacity) to a downstream monopoly carrier.
Airport charges are of two types: a per-passenger charge, denoted \( \tau_q \), and a per-flight
charge (e.g., arrival and departure of an aircraft) denoted \( \tau_f \); both of which are charged
to the carrier. Notice, since the payment of airport charges is separable from other
social costs, the assumption that the per-passenger charge is levied to the carrier (not
passengers) is without loss of generality.\footnote{ICAO (2012) proposes that airport passenger-service charges should be levied through aircraft operators rather than passengers for the purpose of increasing the efficiency of collecting airport charges (noting that there are much less carriers than passengers).} Denote the carrier’s passenger quantity by \( q \geq 0 \) and the quantity of vehicle flights by \( f > 0 \). Aircraft are all of the same size with a non-binding maximum capacity.\footnote{Letting \( \bar{q} \) denote the maximum passenger quantity per flight, load factors can be derived as \( (q/f) / \bar{q} \), where \( q/f \) is the quantity of passengers per flight.} This leads to an infrastructure (airport) revenue of \( \tau_{qq} + \tau_{ff} \). Normalizing the airport’s per-passenger and per-flight costs to zero, the airport profit can be written as

\[
\Pi \equiv \tau_{qq} q + \tau_{ff} f - F,
\]

(1)

where \( F > 0 \) denotes the fixed infrastructure cost. To ensure that airport cost recovery can be achieved, assume that \( F \) is sufficiently small. The carrier’s per-passenger cost is normalized to zero as well, whilst the carrier’s per-flight cost is denoted as \( c > 0 \).\footnote{As pointed in, e.g., Brander and Zhang (1990), once a flight is committed to service, costs per passenger are usually rather small.} Thus, the carrier’s costs include both airport payments and its per-flight operating cost, and can be written as \( \tau_{qq} q + (\tau_{ff} + c) f \). The carrier charges ticket price \( p \) to passengers (simply called “price” in the remainder of the paper), which yields carrier profit

\[
\pi \equiv (p - \tau_{qq}) q - (\tau_{ff} + c) f.
\]

(2)

Turning to the demand side, let \( B \) denote the (gross) travel benefit to passengers with \( B \equiv B(q) \). The benefit function has its usual properties of \( B'(q) > 0 \) and \( B''(q) < 0 \), indicating that the benefit is strictly concave in the passenger quantity. The generalized passenger cost (“full fare”) is composed of the price \( p \) and the per-passenger “schedule delay cost,” with the latter being the cost a passenger incurs for the time between the passenger’s desired departure and the actual departure time. (We assume, as is common in the literature, that consumers are able to place a monetary value on non-price service attributes.) The schedule delay costs of all passengers are obtained by
the multiplication of schedule delays, denoted $\Gamma$, and time valuation, denoted $v$. Letting $\eta$ denote the full fare, it holds that $\eta \equiv p + v\Gamma$. Furthermore, schedule delays depend on flight frequency, that is $\Gamma \equiv \Gamma(f)$. Assume that schedule delays are a strictly convex function in frequency, that is $\Gamma'(f) < 0$ and $\Gamma''(f) > 0$. Consumer surplus ($CS$) and social welfare ($W$) can now be written as

$$CS \equiv B - \eta q \quad \text{and} \quad W \equiv B - qv\Gamma - cf - F, \quad (3)$$

respectively.

Passenger demand is determined by the equilibrium condition $dCS/dq = 0$, which implies

$$B'(q) = \eta, \quad (4)$$

where the left-hand side (LHS) is the marginal benefit, while the right-hand side (RHS) is the full fare. Totally differentiating this equilibrium condition with respect to price and frequency yields, respectively,

$$\frac{\partial q}{\partial p} = \frac{1}{B''(q)} < 0, \quad \text{and} \quad \frac{\partial q}{\partial f} = \frac{v\Gamma'(f)}{B''(q)} > 0. \quad (5)$$

Clearly, the demand is decreasing in price and increasing in frequency because an increase in price raises the full fare, while an increase in frequency reduces the full fare. Furthermore, letting $D$ denote the demand with $q \equiv D(\eta)$, we assume:

**Assumption 1** For $D > 0$,

$$D'(\eta) + (p - \tau_q) D''(\eta) < 0 \quad (6)$$

for sufficiently high but possibly negative values of the per-passenger charge.

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7 According to Douglas and Miller (1974), the schedule delay may be decomposed into “frequency delay” and “stochastic delay.” The former refers to the difference between one’s desired departure time and the closest scheduled departure by the airline, whereas the latter is the delay caused by excess demand for one’s preferred flight(s). Both delays are dependent on flight frequency.

8 This is a standard assumption for non-negative per-passenger charges. Since per-passenger subsidies may be optimal from the carriers’ or the social viewpoints, we complement this assumption in order to ensure that it is also satisfied as long as subsidies are sufficiently low.
Note that $q = D(\eta)$ is determined, implicitly, by (4); consequently, $D'(\eta) = 1/B''(q) < 0$. Assumption 1 is used to ensure the existence of solutions for the carrier’s and welfare-optimal behavior.

The time structure consists of two stages: in the first stage, the per-passenger and per-flight charges are determined in order to ensure airport cost recovery. In order to gradually increase the complexity of the problem, two variations of the setup are considered: (i) the carrier considers frequency as given and chooses price only, and (ii) the carrier simultaneously chooses price and frequency. Note that for our case of a monopoly carrier, the simultaneous choice of price and frequency is without loss of generality relative to the sequential choice of frequency and price.

3 Optimal Mix of Airport Charges

3.1 Fixed frequency

**Carrier’s incentive** Consider the second-stage first. For fixed frequency, the carrier can only choose the price to maximize its profit. From profit expression (2), the first-order condition can be written as (superscript $M$ for the monopoly solution),

$$D(\eta) + (p^M - \tau_q) D'(\eta) = 0,$$

(7)

where Assumption 1 ensures that the second-order condition $\partial^2 \pi / \partial p^2 < 0$ is satisfied in optimum. Totally differentiating (7) with respect to first-stage variable $\tau_q$ yields

$$\frac{dp^M}{d\tau_q} = \frac{D'(\eta)}{\partial^2 \pi / \partial p^2} > 0,$$

(8)

where the inequality follows from the second-order condition and $D'(\eta) < 0$ discussed above. Thus, an increase in the per-passenger charge increases the carrier’s price. This is intuitive, since per-passenger charges determine marginal passenger costs.

The airport cost-recovery constraint clearly is binding from the carrier’s perspective, since any reduction of payments to the airport would increase the carrier profit. This
implies, from (1), that \( \tau_q q + \tau_f f - F = 0 \). Substituting \( \tau_q q + \tau_f f = F \) into (2) (and replacing \( q \) with \( D \)), the carrier profit can be rewritten as

\[
\pi = p^M D - cf - F.
\]

As can be easily seen from (9), the optimal airport-charges structure from the carrier’s viewpoint is purely determined by its effect on carrier revenue when frequency is fixed.

The carrier’s incentive in choosing per-passenger charges can be revealed by examining a situation as if it chose \( \tau_q \), conditional on its second-stage behavior. That is, we can consider the first-order condition \( \partial \pi / \partial \tau_q = 0 \), which leads to

\[
(D(\eta) + p^M D'(\eta)) \frac{dp^M}{d\tau_q} = 0.
\]

As expected, the per-passenger charge should be chosen to induce revenue maximization, since \( dp^M / d\tau_q > 0 \) by (8). The first-order condition in (7) (and \( D'(\eta) < 0 \)) further implies that the optimal per-passenger charge from the carrier’s viewpoint is zero when frequencies are fixed, which means that airport cost recovery should solely be ensured by the per-flight charge \( \tau_f = F/f \).

**Carrier’s versus social incentives** The airport cost-recovery constraint is also binding from the social viewpoint: Letting \( p^* \) denote the welfare-optimal price, the corresponding optimality condition, \( \partial W / \partial p = 0 \), can be written as \( p^* \cdot (\partial q / \partial p) = 0 \), where the second-order condition (i.e., \( \partial^2 W / \partial p^2 < 0 \)) is, again, ensured by Assumption 1. Furthermore, since the demand is, by (5), strictly decreasing in price for \( q > 0 \), the welfare-optimal price and associated carrier revenue are zero (which is natural, since marginal passenger cost is normalized to zero). Furthermore, to implement the welfare-optimal price of zero, passenger traffic must be subsidized by the comparative-static relationship in (8). However, since carrier revenue is zero at the welfare optimum, airport cost recovery cannot be guaranteed because subsidies plus airport fixed costs would have to be covered by per-flight charges. This is, however, not possible without violation of the carrier’s cost-recovery constraint.
To analyze the distinct views on per-passenger charges from the carrier’s and the social viewpoints, consider the unifying objective

\[ V \equiv \pi + \phi CS, \]

where \( \phi \) is called the viewpoint parameter with \( \phi \in [0, 1] \). For \( \phi = 0 \), the objective is maximization of carrier profit, while welfare maximization is considered for \( \phi = 1 \). Notice that the objective in (11) anticipates that the airport cost-recovery constraint is strictly binding from the carrier’s and the social viewpoints.

Assume that the optimal per-passenger charge is determined by the first-order condition \( \partial V / \partial \tau_q = 0 \), which leads to

\[ \frac{\partial \pi}{\partial \tau_q} + \phi \frac{\partial CS}{\partial \tau_q} = 0. \]

At this stage, the use of the viewpoint parameter is helpful because the comparative-static relationship between the optimal per-passenger charge and the viewpoint parameter can be used to identify the potentially distinct views on the optimal mix of airport charges. For instance, if the optimal per-passenger charge is decreasing in the viewpoint parameter, we understand that the carrier’s optimal per-passenger charge is too high from the social viewpoint. Totally differentiating the first-order condition (12) with respect to the viewpoint parameter indeed yields

\[ \frac{d\tau_q}{d\phi} = -\frac{\partial^2 V / \partial \tau_q \partial \phi}{\partial^2 V / \partial \tau_q^2} < 0. \]

The inequality arises because \( \partial^2 V / \partial \tau_q^2 < 0 \) by the second-order condition and

\[ \frac{\partial^2 V}{\partial \tau_q \partial \phi} = \frac{\partial CS}{\partial \tau_q} = -q \frac{dp^M}{d\tau_q} < 0, \]

with the inequality following from (8). This demonstrates the conflicting views on per-passenger charges: While the carrier is interested in maximizing profit, the social optimizer would like to implement the per-passenger subsidy in order to approximate marginal cost pricing in the downstream market, conditional on carrier cost recovery. Thus, the socially optimal per-passenger charge is negative and too low from the carrier’s viewpoint, which favors a zero per-passenger charge.
3.2 Endogenous Frequency

The above analysis demonstrates the conflicting views on the per-passenger charges: While the carrier is interested in a relatively high per-passenger charge, which ensures revenue maximization, the social maximizer is interested in approximating marginal cost pricing in the downstream market. But, note that carriers seem to propose the use of strictly positive per-passenger charges. This behavior seems to be inconsistent with the above results, which are obtained under the condition of fixed flight frequency. To consider a more realistic setup, this section relaxes this condition and considers endogenous frequency.

Carrier’s incentive  With endogenous frequency, the carrier’s behavior is determined by the first-order conditions \( \partial \pi / \partial p = 0 \) and \( \partial \pi / \partial f = 0 \). The former is given in (7), while the latter can be written as

\[
(p^M - \tau_q) D'(\eta) v \Gamma' - (\tau_f + c) = 0. \tag{15}
\]

Using (7), equation (15) can be rewritten as

\[
-Dv\Gamma' - (\tau_f + c) = 0, \tag{16}
\]

which shows that at the carrier optimum, the marginal reduction in schedule delay costs is just offset by the carrier’s marginal frequency costs \((c + \tau_f)\). This is intuitive, since the carrier can fully internalize any reduction in schedule delay costs by an increase in price. To ensure the existence of a solution to (7) and (15), the remainder assumes that the schedule delay function is sufficiently convex (i.e., \(\Gamma''\) is sufficiently large) in the sense that the Hessian of carrier profit with respect to price and frequency

\[
\begin{pmatrix}
\frac{\partial^2 \pi}{\partial p^2} & \frac{\partial^2 \pi}{\partial p \partial f} \\
\frac{\partial^2 \pi}{\partial p \partial f} & \frac{\partial^2 \pi}{\partial f^2}
\end{pmatrix} =
\begin{pmatrix}
2D' + (p - \tau_q) D'' & D'v\Gamma' + (p - \tau_q) D''v\Gamma' \\
(D' + (p - \tau_q) D'') v\Gamma' & (p - \tau_q) D''(v\Gamma')^2 + (p - \tau_q) D'v\Gamma''
\end{pmatrix} \tag{17}
\]
is negative definite in optimum.

Denote \((p^M, f^M)\) to be the solution of the second-stage, which is a function of first-stage airport charges \((\tau_q, \tau_f)\). Totally differentiating (7) and (15) with respect to per-passenger charge \(\tau_q\) and applying Cramer’s rule yields the comparative-static relationships (the proofs of lemmas and propositions are delegated to the appendix):

**Lemma 1** An increase in the per-passenger charge reduces the flight frequency, while increasing the price if the schedule delay function is sufficiently convex. On the other hand, an increase in the per-flight charge reduces both the price and frequency.

Since an increase in the per-passenger charge increases the carrier’s marginal passenger costs, it seems natural that this also increases the price. However, an increase in the per-passenger charge reduces frequency supply, which exerts a downward pressure on the price. The overall effect of an increase in the per-passenger charge is therefore ambiguous in sign. Yet, if the schedule delay function is sufficiently convex (negative definiteness of Hessian (17) is not sufficient for this to hold) an increase in the per-passenger charge has a clear-cut and positive effect on the price, which is assumed to hold in the remainder. That an increase in the per-flight charge increases per-flight costs and thus reduces frequency supply, while that a reduced frequency supply increases schedule delays and thus reduces demand and price is intuitive.

We now examine the carrier’s incentive in choosing per-passenger charges. Similarly to the case of fixed frequency, this is done by looking at the first-order condition \(\frac{\partial \pi}{\partial \tau_q} = 0\). Conditional on airport cost recovery, this leads to

\[
\Delta_p D + p^M D' \cdot \underbrace{\left( \Delta_p + \Delta_f v \Gamma' \right)}_{\Delta n \equiv} - \Delta_f c = 0
\]

with

\[
\Delta_p \equiv \frac{\partial p^M}{\partial \tau_q} + \frac{\partial p^M}{\partial \tau_f} \frac{d \tau_f}{d \tau_q}, \quad \text{and} \quad \Delta_f \equiv \frac{\partial f^M}{\partial \tau_q} + \frac{\partial f^M}{\partial \tau_f} \frac{d \tau_f}{d \tau_q}
\]

and \(\partial^2 \pi / \partial \tau_q^2 < 0\) by the second-order condition.

An increase in the per-passenger charge leads to a “price effect,” denoted as \(\Delta_p\), and a “frequency effect,” denoted as \(\Delta_f\). The price effect measures how an increase in \(\tau_q\)
changes price; this effect is positive because this increase in \( \tau_q \) directly and indirectly increases price through the corresponding reduction in the per-flight charge, which stimulates frequency supply.\(^9\) The frequency effect measures how an increase in the per-passenger charge changes flight frequency; this effect can be positive or negative in sign because an increase in \( \tau_q \) directly reduces frequency, while it indirectly increases frequency as it reduces the per-flight charge. To concentrate on the trade-off between price and frequency, we assume in the remainder of the paper that the frequency effect \( \Delta_f \) is positive in sign.

Using these definitions of price and frequency effects, there is a clear interpretation of the LHS of (18). The first two terms on the LHS show the change in revenues associated with a marginal increase in the per-passenger charge, which is composed of (i) the change in revenues associated with the change in the price, and (ii) the change in revenues associated with the change in the full fare, which is denoted as \( \Delta \eta \) with \( \Delta \eta \equiv \Delta_p + \Delta_f v \Gamma' \), multiplied with the corresponding change in the passenger quantity. The third term shows the increase in frequency costs associated with a marginal increase in the per-passenger charge, which is positive because of the corresponding reduction of the per-flight charge. Then, the per-passenger charge is optimal when the revenue and cost effects are equalized in absolute values.

To see when the carrier can benefit from a strictly positive per-passenger charge, expand the LHS of (18), and note that the new first two terms, \( \Delta_p ( D + p^M D' ) \), are zero when the per-passenger charge is zero, which holds true by the first-order condition in (7). Then, whether the carrier would be better off with an increase in \( \tau_q \) depends on the sign of the frequency effect alone. Specifically, we have the following results:

**Proposition 1** (i) If flight frequency is fixed, the optimal per-passenger charge from the carrier’s viewpoint is equal to zero. (ii) If flight frequency is endogenously chosen by the carrier, the optimal per-passenger charge from the carrier’s viewpoint is strictly

\(^9\)The zero airport-profit contour can be upwardsloping in the \( \tau_q-\tau_f \)-space. Since reductions in the per-passenger or per-flight charges can increase carrier profit and welfare, only the downward-sloping parts of this contour is relevant for our analysis, however.
Thus, when frequency is endogenous, the carrier benefits from a strictly positive per-passenger charge, since the associated reduction in the per-flight charge increases flight frequency in a situation where the schedule delay cost exceeds the additional frequency cost.

**Carrier’s versus social incentives** We first demonstrate that the airport cost-recovery constraint is binding from the social viewpoint when frequency is endogenously determined by the carrier. Assume that the welfare-optimal carrier behavior is determined by the first-order conditions $\partial W/\partial p = 0$ and $\partial W/\partial f = 0$.\footnote{The concavity of the welfare function in price and frequency can again be ensured by the convexity of the schedule delay costs.} Recall that this means that the price is zero. Substituting $p$ by zero, the condition $\partial W/\partial f = 0$ can be written as

$$-Dv\Gamma' - c = 0. \quad (20)$$

Comparing the conditions (20) and (16) reveals that the carrier’s frequency choice is optimal from the social viewpoint if and only if the per-flight charge is zero. Since the carrier must be subsidized to achieve the first-best price, while the first-best per-flight charge is zero, the airport cost-recovery constraint is strictly binding from the carrier’s and the social viewpoints.

It is useful to understand that the frequency supply can be considered as a quality dimension (high frequency reduces passenger schedule delays) and thus the finding that monopoly frequency supply is socially optimal is anticipated by the analyses of Spence (1975) and Sheshinski (1976), who showed that the monopoly quality supply is optimal from the social viewpoint if the quality valuation of the marginal customer is representative for all customers. Since time valuations are assumed to be the same for all passengers in our basic set-up, monopoly frequency supply is socially optimal (for given quantity) when the per-flight charge is zero.
To identify the differences between the carrier’s and the social viewpoints, consider the sign of the cross-derivative of $V$ with respect to the viewpoint parameter and the per-passenger charge when frequency is endogenous, which can be written as

$$\frac{\partial CS}{\partial \tau_q} = -\Delta \eta D. \quad (21)$$

Notice that $\Delta \eta$ can be positive or negative in sign, while consumer surplus would be maximized when the full fare is minimized in the sense that the marginal effect of a change in the per-passenger charge on the full fare conditional on airport cost recovery is zero.

This leads to:

**Proposition 2** (i) The carrier’s and the social viewpoints are identical only if the optimal mix of airport charges minimize full fares conditional on airport cost recovery. (ii) The zero per-flight charge is a necessary and a sufficient condition for the carrier’s viewpoint and the social viewpoint to be identical, while the carrier’s preferred per-passenger charge is excessive (too low) from the social viewpoint when the carrier’s preferred per-flight charge is positive (negative).

For an intuitive explanation for why the carrier’s and the social viewpoints can be conflicting, note that the social optimizer attaches a higher weight (in absolute values) to changes in full fares than the carrier because the social optimizer also cares about consumer surplus. But, the carrier’s and the social viewpoints are not always conflicting, and the carrier’s preference for the per-flight charge indicates whether the carrier’s and the social viewpoints may be identical or conflicting by Proposition 2. Specifically, if a zero per-flight charge is optimal from the carrier’s viewpoint, then the carrier’s and the social viewpoint must be identical.

**Example 1** This example is used to show that the optimal per-passenger charge from the carrier’s viewpoint may be too low from the social viewpoint. To show this, assume
that schedule delays are given by $\Gamma = 1 - f + f^2/2$ for $f < 1$.\footnote{Since schedule delays are highly non-linear in frequency, the analytical solutions are difficult to interpret. The following therefore relies on specific parameter instances (the same is true for Example 2 below).} Furthermore, assume that the benefit function is

$$B(q) = 3q - 5q^2/4,$$ \hfill (22)

the time valuations are given by $v \in \{1/5, 2/5, 5/2\}$, the marginal frequency cost by $c = 1/10$, and the fixed airport cost by $F = 1/10$. Figures 1-3 display iso-carrier profit (dashed line), iso-airport profit (thin solid line) and iso-welfare (thick solid line) curves in the $\tau_q-\tau_f$ space. The iso-airport curve displays the combinations of per-passenger and per-flight charges that yield exact airport cost recovery ($\Pi = 0$). Since a reduction in airport charges can increase carrier profit and welfare, the optimal mix of airport charges can be derived by identification of the iso-carrier and iso-welfare curves, which are tangent to the iso-airport profit curve. All iso-curves are downward sloping in the relevant regions, which illustrates the trade-off between increases in per-passenger or per-flight charges. In these instances, it holds that the carrier’s optimal per-passenger charge is excessive from the social viewpoint when $v = 5/2$, they are exactly the same when $v = 2/5$ and the carrier’s optimal per-passenger charge is too low from the social viewpoint when $v = 1/5$. In this sense, the carrier’s optimal per-passenger charge is more likely to be excessive from the social viewpoint if time valuations are high.

4 Passenger Types

There are two types of passengers called business and leisure passengers. Letting $q^B$ and $q^L$ denote the business and leisure passenger quantities (simply called the business and leisure quantities), respectively, the travel benefits now become $B^T \equiv B^T(q^L, q^B)$. The Hessian of the benefits with respect to the business and leisure quantities is assumed to be negative definite, which means that the benefits are a strictly concave function of the passenger quantities (superscript $T$ indicates the scenario with two passenger types
Figure 1: Iso-carrier profit (dashed line; carrier profit is 0.43), iso-airport profit (thin solid line; airport profit is zero), and iso-welfare (thick solid line; welfare is 0.80) curves with uniform prices: the carrier’s optimal per-passenger charge is excessive from the social viewpoint. Parameters: $a = 3, b = 5/2, v = 1, c = F = 1/10$. 
Figure 2: Iso-carrier profit (dashed line; carrier profit is 0.60), iso-airport profit (thin solid line; airport profit is zero), and iso-welfare (thick solid line; welfare is 1.03) curves with uniform prices: the carrier’s and the social viewpoints are in line. Parameters: $a = 3, b = 5/2, v = 2/5, c = F = 1/10$. 

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Figure 3: Iso-carrier profit (dashed line; carrier profit is 0.68), iso-airport profit (thin solid line; airport profit is zero), and iso-welfare (thick solid line; welfare is 1.13) curves with uniform prices: the carrier’s optimal per-passenger charge is too low from the social viewpoint. Parameters: $a = 3, b = 5/2, v = 1/5, c = F = 1/10$. 
and uniform pricing). Since business passengers typically have a greater value of time, assume that the business full fare is \( \eta_B \equiv p + v_B \Gamma \) and leisure full fare \( \eta_L \equiv p + v_L \Gamma \), where \( v_B \) is the business passengers’ time valuation, \( v_L \) is the leisure passengers’ time valuation with \( v_B \geq v_L (\geq 0) \), and \( p \) is the uniform price charged to both the business and leisure passengers.\(^{12}\) Consumer surplus can now be written as

\[
CST \equiv B^T - \eta_B q_B - \eta_L q_L.
\] (23)

Assume that the demand equilibrium is determined by the conditions \( CST_B = 0 \) and \( CST_L = 0 \) (with subscripts indicating partial derivatives, e.g. \( \partial f / \partial x \equiv f_x \) here and in the remainder of the paper), which implies \( B_B^T = \eta_B \) and \( B_L^T = \eta_L \). Totally differentiating these equilibrium conditions with respect to the price and, respectively, frequency, yields

\[
\frac{dq_B}{d\eta_B} = B_{BB}^T / \Phi \quad \text{and} \quad \frac{dq_L}{d\eta_L} = B_{BB}^T / \Phi
\] (24)

with

\[
\Phi \equiv \det \begin{pmatrix} B_{BB}^T & 0 \\ 0 & B_{LL}^T \end{pmatrix} = B_{BB}^T B_{LL}^T > 0
\] (25)

by the negative definiteness of the Hessian of \( B^T \). To ensure that group-specific benefits are separable, \( B_{BL}^T = 0 \) is assumed to hold.\(^{13}\) The relationships in (24) can be used to derive how passenger quantities change in the uniform price and frequency:

\[
\frac{\partial q}{\partial p} = \frac{dq_B}{d\eta_B} + \frac{dq_L}{d\eta_L} = B_{BB}^T + B_{LL}^T
\] (26)

and

\[
\frac{\partial q}{\partial f} = \left( v_B \frac{dq_B}{d\eta_B} + v_L \frac{dq_L}{d\eta_L} \right) \Gamma' = \left( v_B B_{BB}^T + v_L B_{LL}^T \right) \Gamma'.
\] (27)

\(^{12}\)Morrison (1987), Morrison and Winston (1989), USDOT (1997), and Pels et al. (2003) found that time valuations related to congestion are distinct, while we concentrate on schedule delays. Based on this empirical evidence, it seems however sensible to assume that business passengers’ time valuation may also be higher than leisure passengers’ time valuation when schedule delays are considered.

\(^{13}\)Separability is important to ensure that changes in the business passenger quantity can be independent of changes in the leisure passenger quantity. For example, this rules out that time valuations depend on whether passengers buy a business or a leisure ticket.
Clearly, demand is decreasing in the price and increasing in frequency due to the negative definiteness of the Hessian of benefits with respect to quantities and because an increase in the price increases full fares, while an increase in frequency reduces full fares.

4.1 Uniform price

The motivation to consider passenger types with distinct time valuations is related to the fact that this changes the carrier’s incentives to provide flight frequency and, hence, the optimal mix of airport charges. The following therefore concentrates on the endogenous supply of frequency and abstracts away from the possibility that frequency may be fixed.

**Carrier’s incentive** Denote the business and leisure demands as $D_B \equiv D_B(\eta_B) \equiv q_B(\eta_B)$ and $D_L \equiv D_L(\eta_L) \equiv q_L(\eta_L)$, respectively, as well as the aggregate demand as $D^T \equiv D_B + D_L$. Substituting $D^T$ for $D$ in profit function (2) then yields profit when passengers with distinct time valuations exist, which is denoted as $\pi^T(p, f)$. This leads to the first-order conditions $\partial \pi^T / \partial p = 0$ and $\partial \pi^T / \partial f = 0$, which can be written as

$$D^T + (p^T - \tau_q) (D_B' + D_L') = 0$$

(28)

and

$$(p^T - \tau_q) (v_B D_B' + v_L D_L') \Gamma' - (c + \tau_f) = 0,$$

(29)

where $p^T$ are the monopoly prices. Using (28), condition (29) can be rewritten as

$$-D^T \hat{v} \Gamma' - (c + \tau_f) = 0$$

(30)

with

$$\hat{v} \equiv \frac{D_B' v_B + D_L' v_L}{D_B' + D_L'},$$

(31)

where the latter defines average time valuation of incremental passengers called the “marginal passengers’ time valuations” (see, Czerny and Zhang (2014a and 2014b), who concentrate on congestion effects). This shows that the monopoly carrier evaluates the
reduction in schedule delays associated with a marginal increase in frequency with the marginal passenger’s time valuation. Since schedule delays can be considered as a quality dimension, the fact that the monopoly carrier is concerned about the marginal time valuations is consistent with the findings by Spence (1975) and Sheshinski (1976), who showed that a monopoly supplier is concerned about the marginal customers’ quality valuations.

Letting $\overline{\nu}$ denote the average time valuations with $\overline{\nu} \equiv (v_B D_B + v_L D_L) / D^T$, the remainder assumes that the elasticity condition

$$D'_L / D_L < D'_B / D_B$$

(Elasticity condition)

is satisfied, which implies that marginal time valuations are less than average time valuations, i.e. $\hat{\nu} < \overline{\nu}$.15

To derive the optimal mix of airport charges from the carrier’s viewpoint, one needs to understand the comparative-static relationships between airport charges and the uniform price. These can be derived as:16

**Lemma 2** If passengers with distinct time valuations exist (i.e., $v_L \leq v_B$) and prices are uniform, it holds that: (i) An increase in the per-passenger charge increases the equilibrium price, while frequency is also increased if time valuations are sufficiently distinct, business demands are concave and leisure demands are convex (evaluated at the optimum). (ii) An increase in the per-flight charge reduces both the monopoly price and frequency.

---

14To ensure that the Hessian of profit with respect to the uniform price and frequencies is negative definite, apply Assumption 1 to $D^T$.

15Substituting $(1 - D'_L / (D'_L + D'_B))$ for $D'_B / (D'_L + D'_B)$ and $(1 - D_L / D^T)$ for $D^B / D^T$, one can show that for $D_B, D_L > 0$, $\hat{\nu} < \overline{\nu}$ when $D'_L / (D'_L + D'_B) > D_L / D^T$, which is equivalent to the elasticity condition. In words, the elasticity condition implies that incremental passengers exert a high proportion of leisure passengers relative to inframarginal passengers.

16The following analysis assumes that schedule delays are “sufficiently convex” evaluated at (uniform or discriminating) prices in a way, which will be made precise in the proofs of lemmas and propositions.
The main difference relative to the case with uniform time valuation is that an increase in the per-passenger charge may lead to an increase in flight frequency when passengers with distinct time valuations exist. The intuition is related to the fact that an increase in the per-passenger charge may be associated with a reduction in the aggregate passenger quantity and an increase in marginal time valuation, which increases the carrier’s incentive to provide frequency. Notice that the reduction in aggregate quantity may be particularly large when leisure demands are convex, while the reduction in business quantity may be relatively low when business demands are concave evaluated at the optimum, which can altogether lead to a sharp increase in marginal time valuations and, hence, in the incentives to provide frequency.

Assume that the optimal per-passenger charge from the carrier’s viewpoint is determined by the first-order condition $\frac{\partial \pi^T}{\partial \tau_q} = 0$ leading to

$$
\Delta_p^T D^T + p^T (D_B + D_L^c) (\Delta_f^T + \Delta_f^T \tilde{\gamma}') - \Delta_f^T c = 0
$$

(32)

with

$$
\Delta_p^T \equiv \frac{\partial p^T}{\partial \tau_q} + \frac{\partial p^T}{\partial \tau_f} \frac{\partial \tau_f}{\partial \tau_q} \quad \text{and} \quad \Delta_f^T \equiv \frac{\partial f^T}{\partial \tau_q} + \frac{\partial f^T}{\partial \tau_f} \frac{\partial \tau_f}{\partial \tau_q}
$$

(33)

and $\frac{\partial^2 \pi^T}{\partial \tau_q^2} < 0$ by the second-order condition. As before (with uniform time valuations), an increase in the per-passenger charge leads to a price effect, denoted as $\Delta_p^T$, and a frequency effect, denoted as $\Delta_f^T$. For similar reasons as the ones described for the case of uniform time valuations in Section 3.2, assume that the price and the frequency effects are both strictly positive in sign.\footnote{Since an increase the per-passenger charge may increase frequency supply by Lemma 2, this seems a more restrictive assumption here relative to the scenario with uniform time valuations. To demonstrate how the existence of passenger types with distinct time valuations can change the picture with respect to optimal airport-charges structures, it is however sufficient to concentrate on the cases where $\Delta_p^T > 0$ and $\Delta_f^T > 0$.}

Note that the first-order condition (32) weights the frequency effect at marginal time valuations. Thus, the carrier attaches a relatively low weight to the frequency effect, since marginal time valuations are low relative to average time valuations. Still,
the carrier’s optimal per-passenger charge is strictly positive in the sense described by Proposition 1 for the case of uniform time valuations.\textsuperscript{18}

**Carrier’s versus social incentives** To show that the airport cost-recovery constraint is binding from the social perspective, we write welfare as

\[
W^T \equiv B^T - D^T \pi T - cf - F.
\]  
(34)

Assume that the welfare optimal price and the welfare optimal frequency are determined by the first-order conditions \( \partial W^T / \partial p = 0 \) and \( \partial W^T / \partial f = 0 \), respectively. These imply

\[
(D'_B + D'_L) p^T = 0 \text{ and } -D^T \pi T' - c = 0.
\]  
(35)

This shows that strictly negative per-passenger and per-flight charges are required to implement the first-best solution. Recall, with uniform time valuations, a zero per-flight charge was required to implement the first-best result. In this sense, the airport cost-recovery constraint is “more” binding when passengers with distinct time valuations exist relative to a scenario with uniform time valuations because the carrier is concerned with marginal time valuations.

Anticipating that the airport cost-recovery constraint is binding from the carrier’s and the social viewpoints, we concentrate on the objective \( V^T \equiv \pi^T + \phi CS^T \), where the second term on the RHS involves consumer surplus

\[
CS^T \equiv B^T - (\eta_B D_B + \eta_L D_L).
\]  
(36)

The sign of the cross-derivative \( \partial^2 V^T / \partial \phi \partial \tau_q \) yields

\[
\frac{\partial CS^T}{\partial \tau_q} = - \left( \Delta^T_p + \Delta^T_f \pi T' \right) D^T.
\]  
(37)

Incorporating the consumers’ perspectives thus means that full fares evaluated at average time valuations should be minimized. The optimal per-passenger charges are determined by the first-order condition \( \partial V^T / \partial \tau_q = 0 \), and (37) can be used to derive:

\textsuperscript{18}The proof is analogous to the proof of Proposition 1 and omitted here.
Proposition 3 If passengers with distinct time valuations exist and prices are uniform, it holds that: (i) The carrier’s and the social viewpoints are identical only if the optimal mix of airport charges minimizes full fares evaluated at average time valuations, \( \bar{\tau} \), conditional on airport cost recovery. (ii) The optimal mix of airport charges from the carrier’s and the social viewpoints can be identical only if they incorporate a positive per-flight charge and a positive per-passenger charge.

The social maximizer is concerned with average full fares, and therefore the carrier’s optimal mix of airport charges is also optimal from the social viewpoint only if they minimize average full fares conditional on airport cost recovery, which provides an intuition for part (ii) of Proposition 3. The intuition for part (ii) is based on the fact that the carrier’s incentives to reduce the per-flight charge are lowered by the existence of passenger types with distinct time valuations. This is because the associated profit gains from increased frequency are evaluated by marginal time valuations, which are low relative to average time valuations. Therefore, the carriers’ and the social incentives can be identical only if the optimal mix of airport charges incorporates a positive per-flight charge. Yet, the fact that the carrier’s incentives to increase frequency are too low from the social viewpoint means that the social maximizer may want to charge a relatively high per-passenger charge, which can be used to reduce the per-flight charge and stimulate frequency supply. Altogether, this implies that the carrier’s preferred per-passenger charge is, in a sense, less likely to be excessive from the social viewpoint, but may rather be too low.

From this discussion it is also clear that, if the optimal per-flight charge and the optimal per-passenger charge are both positive from the carrier’s viewpoint, this is not a sufficient condition for the carrier’s and the social viewpoints to be in line because the social optimizer may well prefer a negative per-flight charge under these conditions. Example 2 below is used to illustrate this.
4.2 Discriminating prices

To consider discriminating prices in the sense of third-degree price discrimination when all markets are covered, assume that the carrier can charge prices $p_B$ to business passengers and $p_L$ to leisure passengers (e.g., Czerny and Zhang 2014a). This leads to full fares $\eta_B^D \equiv p_B + v_B \Gamma$ and $\eta_L^D \equiv p_L + v_L \Gamma$ (where superscript $D$ stands for discrimination). The carrier profit then becomes

$$\pi^D \equiv (p_B - \tau_q) D_B + (p_L - \tau_q) D_L - (c + \tau_f) f.$$  \hfill (38)

First-order conditions for prices are $\partial \pi^D / \partial p_B = 0$ and $\partial \pi^D / \partial p_L = 0$, which can be written as

$$D_B + (p_B^D - \tau_q) D'_B = 0 \text{ and } D_L + (p_L^D - \tau_q) D'_L = 0,$$  \hfill (39)

where the elasticity condition implies that business prices are high relative to the leisure prices (i.e., $p_L^D < p_B^D$).

Assume that frequencies are determined by the first-order condition $\partial \pi^D / \partial f = 0$. Using the first-order conditions (39), the first-order condition for frequency can be written as

$$-D^T \pi \Gamma' - (c + \tau_f) = 0.$$  \hfill (40)

This shows that the carrier is concerned about average time valuations when prices are discriminating. This is because with price discrimination the carrier can internalize any reductions in schedule delay costs by changes in passenger type-specific prices.

On the other hand, the possibility to price discriminate between business and leisure passengers leaves the pricing behavior of a social maximizer unchanged because the welfare-optimal prices are uniform.\footnote{Czerny and Zhang (2011 and 2013) showed a similar result for a congested airport.} Furthermore, since the carrier is concerned about average time valuations when prices are discriminating between business and leisure passengers, there is no need for the social maximizer to subsidize or penalize frequency supply. The airport cost-recovery constraint is therefore binding from the social perspective whether prices are uniform or discriminating. In this sense, this restores the
results derived by the initial analysis, which concentrates on uniform time valuations, where the carrier’s and the social view on frequency were fully identical only if the optimal per-passenger charge would be zero. Furthermore, this indicates that the carriers’ preferred per-passenger charge may be more likely to be excessive from the social viewpoint because the social incentives to increase the per-passenger charge are reduced relative to a situation with uniform prices when time valuations are distinct between business and leisure passengers.

Example 2  This example illustrates that the optimal per-passenger charge may be too low from the social viewpoint when the carrier charges a uniform price to business and leisure passengers, while the reverse would be true under price discrimination. To show this, assume that benefits are

\[ B^T = \sum_{x=B,L} \left( a_x q_x - b_x \frac{q_x^2}{2} \right) \]  (41)

with \( a_x, b_x > 0 \) and \( a_B \) sufficiently high in order to ensure that the carrier would like to charge a higher price to business passengers relative to leisure passengers. For schedule delays, it holds \( \Gamma = 1/f \).

Figures 4 and 5 display iso-carrier profit (dashed lines), iso-airport profit (thin solid line) and iso-welfare (thick solid line) curves in the \( \tau_q-\tau_f \)-space for parameters \( a_B = 4, b_B = 2, a_L = 1, b_L = 1/2, v_B = 1, v_L = 0, c = 1/10 \) and \( F = 1/2 \). Figure 4 displays the optimal mix of airport charges when prices are uniform. In this situation, the carrier’s incentives to provide frequency are too low from the social viewpoint; thus, to increase frequency supply, the socially optimal per-passenger charge is high relative to the carrier’s preferred per-passenger charge. The opposite is, however, true when the carrier charges discriminating prices to business and leisure passengers. This is because discriminating prices increase the carrier’s incentives to provide frequency as can be seen by inspection of Figure 5.
Figure 4: Iso-carrier profit (dashed line; carrier profit is approximately 0.64), iso-airport profit (thin solid line; airport profit is zero), and iso-welfare (thick solid line; welfare is approximately 2.22) curves with uniform prices: the carrier’s optimal per-passenger charge is too low from the social viewpoint. Parameters: $a_B = 4, b_B = 2, a_L = 1, b_L = 1/2, v_B = 1, v_L = 0, c = 1/10, F = 1/2$. 
Figure 5: Iso-carrier profit (dashed line; carrier profit is approximately 1.33), iso-airport profit (thin solid line; airport profit is zero), and iso-welfare (thick solid line; welfare is approximately 2.18) curves with discriminating prices: the carrier’s optimal per-passenger charge is excessive from the social viewpoint. Parameters: $a_B = 4, b_B = 2, a_L = 1, b_L = 1/2, v_B = 1, v_L = 0, c = 1/10, F = 1/2$. 
5 Conclusions

Airport charges are largely determined by the quantity of aircraft flights, while carriers recently raised the point that passenger related charges should be used to ensure airport cost recovery. This paper has addressed this issue by comparing the carriers’ and the social viewpoints on the optimal mix of airport charges conditional on airport cost recovery through revenues derived from airport per-passenger and per-flight charges. A crucial element of the model is that passengers experience schedule delays, which are negatively related to the quantity of aircraft flights, i.e. frequency. In this case, passenger demands depend on full fares, which are composed of prices and schedule delay costs. The model therefore established a clear trade-off between low per-passenger charge, low price, high load factor and low frequency versus low per-flight charge, high price, low load factor and high frequency.

To analyze this trade-off, a basic scenario with a monopoly carrier and a single passenger type, and later an extension including passenger types (i.e., business and leisure) with differences in time valuations, have been considered. Our analysis showed that carriers can indeed benefit from a positive per-passenger charge relative to zero per-passenger charge because the associated reduction in the per-flight charge increases frequency and profit. On the other hand, if passengers have distinct time valuations, the carrier’s incentive to provide frequency and the profit gain from reductions in the per-flight charge may be reduced when prices are uniform. This is because carriers are concerned with marginal time valuations under these conditions. This effect however disappears when the business and leisure prices are discriminating. Altogether, the present analysis helped one to understand the carriers’ effort to strengthen the role of per-passenger based airport charges.

Turning to the social maximizer, she cares about carrier profits and consumers, and incorporating the consumers’ viewpoint means minimization of full fares conditional on airport cost recovery. In effect, the carrier’s and the social viewpoints can be identical only if the carrier’s preferred mix of airport charges minimizes full fares conditional on
airport cost recovery. We further showed that the carrier’s and the social preferences may be identical only if the carrier’s preferred per-flight charge is exactly equal to zero. This result can facilitate the policy makers’ effort to identify potential conflicts of interest with carriers. Specifically, the carriers’ interest in positive per-passenger charges are consistent with the zero per-flight charge and thus with a situation where the carriers’ and the social viewpoints are indeed identical. Thus, we did not find strong evidence for a conflict of interest between the carriers’ and the social maximizer’s positions.

Our analysis has assumed that frequency supply reduces schedule delay costs, but abstracted away from the possibility that it incurs congestion and raises passenger costs. In effect, our analysis is sufficiently general and also holds for congested airports as long as it is ensured that schedule delay effects dominate congestion delay effects, which rules out that an increase in frequency increases full fares for given prices. The analysis of airports where congestion effects are dominant is left for future research. Another important avenue for future research clearly is to derive empirical evidence of the effect of airport charges structures on prices and frequencies.

The present paper has intentionally abstracted away from oligopolistic airline markets, which are considered in a companion paper (Czerny and Zhang, 2014b). An important feature of oligopolistic markets is that the time structure of decisions becomes important. Specifically, airline ticket prices often change on a daily basis, while flight schedules typically hold for a minimum of half a year. The companion paper therefore employs the assumption that carriers choose frequencies prior to prices. Importantly, the sequential time structure allows us to distinguish between the short- and long-run effects of airport charges structures, where the short-run effects are derived for fixed frequency supplies, while prices and frequencies are considered as endogenous in the long run. Interestingly, also the analysis of the oligopolistic carrier markets provides no strong evidence for a conflict of interest between the carrier’s and the social maximizer’s positions.
References


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Appendix

A Proofs

Lemma 1 Let $\Omega(>0)$ denote the determinant of the Hessian in (17). Cramer’s rule can be used to show that an increase in the per-passenger charge increases the price for a sufficiently convex schedule delay function and reduces frequency:

\[
\frac{\partial p^M}{\partial \tau_q} = \frac{1}{\Omega} \det \begin{pmatrix}
D' & \frac{\partial^2 \pi}{\partial p \partial f} \\
D'v\Gamma' & \frac{\partial^2 \pi}{\partial f^2}
\end{pmatrix}
\]

\[
= \frac{1}{\Omega} \left(-D'Dv\Gamma'' - 2(D'v\Gamma')^2 + DD''(v\Gamma')^2\right),
\]

which is ambiguous sign, while it is positive in sign for $\Gamma''$ sufficiently high, and

\[
\frac{\partial f^M}{\partial \tau_q} = \frac{(D')^2 v\Gamma'}{\Omega},
\]

which is negative in sign. Analogously, the comparative-static relationships between price, frequency and the per-flight charge can be derived as:

\[
\frac{\partial p^M}{\partial \tau_f} = -\frac{\partial^2 \pi}{\partial p \partial f}/\Omega < 0, \quad \text{and} \quad \frac{df^M}{d\tau_f} = \frac{\partial^2 \pi}{\partial f^2}/\Omega < 0.
\]

The first relationship is negative in sign by Assumption 1, while the second relationship is also negative in sign by the second-order conditions.

Proposition 1 Part (i) has been shown in the previous subsection. We now prove part (ii). Suppose that the per-passenger charge is zero at the carrier optimum. In this situation, the first-order condition in (18) can be rewritten as

\[
(-Dv\Gamma' - c) \Delta_f = 0.
\]

Airport cost recovery then requires that the per-flight charge is strictly positive, which means that the bracketed term is strictly positive by the first-order condition (15) or (16). Given that the frequency effect, $\Delta_f$, is strictly positive, this is a contradiction.
Furthermore, since the LHS of equation (45) is strictly positive when the per-passenger charge is zero and the frequency effect is positive, the optimal per-passenger charge is strictly positive by the second-order condition $\partial^2 \pi / \partial \tau_q^2 < 0$.

**Proposition 2** To establish part (i), consider the first-order condition $\partial V / \partial \tau_q = 0$, which can be written as

$$
\Delta_p D - \Delta_f c + \Delta \eta \left( p^M D' - \phi D \right) = 0. \quad (46)
$$

Since $(p^M D' - \phi D)$ is strictly negative in sign, the carrier’s and the social viewpoints can be identical only if full fares are minimized conditional on airport cost recovery, i.e. $\Delta \eta = 0$.

To establish part (ii), suppose the full fares are minimized at the carrier optimum, which implies $\Delta_p = -\Delta_f v \Gamma'$. Substituting $\Delta_p$ for $-\Delta_f v \Gamma'$ in the first-order condition (46) yields

$$
\Delta_f (-v \Gamma' D - c) = 0, \quad (47)
$$

which shows that the zero per-flight charge is a necessary condition for the carrier’s and the social viewpoints to be identical by the first-order condition (16). To show that the zero per-flight charge is not only a necessary but also a sufficient condition for the carrier’s and the social viewpoints to be identical asks the question whether a zero per-flight charge may be optimal from the carrier’s viewpoint when full fares are not minimized. Consider the first-order condition (16), again. Substituting $c$ by $-v \Gamma' D - \tau_f$, the expression $\Delta_p D - \Delta_f c$ can be rewritten as $\Delta \eta D + \tau_f D$. The first-order condition (46) can then be rewritten as

$$
\Delta \eta \left( D + p^M D' \right) + \tau_f D = 0 \quad (48)
$$

for $\phi = 0$ (the latter is used because only the carrier’s viewpoint is relevant here). Since $(D + p^M D') = \tau_f = 0$ is a contradiction because it implicitly assumes a zero per-passenger charge by the first-order condition in (7), the LHS shows that a zero
per-flight charge can be optimal from the carrier’s viewpoint only when full fares are minimized.

The first-order condition (48) can be used to infer whether the carrier’s optimal per-passenger charge may be excessive or too low from the social viewpoint. Recall that the carrier’s preferred per-passenger charge is always strictly positive. Then, if the optimal per-passenger and per-flight charges are positive from the carrier’s viewpoint, \( \Delta \eta > 0 \) and \( (D + p^M D') < 0 \) in the carrier optimum by the first-order condition (7), which means that the carrier’s optimal per-passenger charges are excessive from the social viewpoint by the first-order condition (46). This is because an increase in the per-passenger charge increases full fares in the carrier optimum, which is more important for the social optimizer than for the carrier. On the other hand, if the carrier’s optimal airport-charges structures incorporates a negative per-flight charge and a positive per-passenger charge, (48) implies that \( \Delta \eta < 0 \), which means that the carrier’s optimal per-passenger charge is too low from the social viewpoint.

**Lemma 2** Denote the determinant of the Hessian of profit \( \pi_T \) with respect to the uniform price and frequency as \( \Upsilon \) with

\[
\Upsilon \equiv \det \begin{pmatrix}
\frac{\partial^2 \pi_T}{\partial p^2} & \frac{\partial^2 \pi_T}{\partial p \partial f} \\
\frac{\partial^2 \pi_T}{\partial p \partial f} & \frac{\partial^2 \pi_T}{\partial f^2}
\end{pmatrix}, \quad (49)
\]

which is positive by the second-order condition (i.e., \( \Upsilon > 0 \) in optimum). Cramer’s rule can be used to derive the relationships between the uniform price and the per-passenger charge as well as frequency and the per-passenger charge as

\[
\frac{dp^T}{d\tau_q} = \frac{1}{\Upsilon} \det \begin{pmatrix}
-\frac{\partial^2 \pi_T}{\partial p \partial \tau_q} & \frac{\partial^2 \pi_T}{\partial p \partial f} \\
-\frac{\partial^2 \pi_T}{\partial f \partial \tau_q} & \frac{\partial^2 \pi_T}{\partial f^2}
\end{pmatrix}, \quad (50)
\]

with

\[
\frac{\partial^2 \pi_T}{\partial p \partial \tau_q} = -(D_B' + D_L'), \quad \frac{\partial^2 \pi_T}{\partial f \partial \tau_q} = -(v_B D_B' + v_L D_L') \Gamma' \quad (51)
\]
\[ \frac{\partial^2 \pi^T}{\partial p^2} = 2(D_B' + D_L') + (p - \tau_q)(D''_B + D''_L) \]  
(52)

\[ \frac{\partial^2 \pi^T}{\partial p \partial f} = (D_B' + D_L') \hat{\psi} \Gamma' + (p - \tau_q)(v_B D''_B + v_L D''_L) \Gamma' \]  
(53)

\[ \frac{\partial^2 \pi^T}{\partial f^2} = (p - \tau_q)(v_B D''_B + v_L D''_L)(\Gamma')^2 + (p - \tau_q)(D'_B + D'_L) \hat{\psi} \Gamma''. \]  
(54)

The RHS of (50) is clear-cut and positive in sign when schedule delays are sufficiently convex (meaning that \( \hat{\psi} \Sigma \hat{\psi} \) is sufficiently high in absolute values).

The effect of a marginal increase in the per-passenger charge can be derived as

\[ \frac{df^T}{d\tau_q} = \frac{1}{\Gamma} \det \begin{pmatrix} \frac{\partial^2 \pi^T}{\partial p^2} & D'_B + D'_L \\ \frac{\partial^2 \pi^T}{\partial p \partial f} & (v_B D'_B + v_L D'_L) \Gamma' \end{pmatrix} \]  
(55)

with

\[ \det \begin{pmatrix} \frac{\partial^2 \pi^T}{\partial p^2} & D'_B + D'_L \\ \frac{\partial^2 \pi^T}{\partial p \partial f} & (v_B D'_B + v_L D'_L) \Gamma' \end{pmatrix} = \left( (D'_B + D'_L)^2 (D'_B + D'_L) \hat{\psi} + (p - \tau_q) [(v_B - v_L) (D''_B D''_L - D'_L D'_B)] \right) \Gamma'. \]  
(56)

The RHS of (55) implies that an increase in the per-passenger charge increases frequency when leisure demands are convex, business demands are concave (which together implies \( D''_B D''_L - D'_L D'_B < 0 \)) and time-valuations between business and leisure passengers are sufficiently distinct. Clearly, if time valuations are uniform, an increase in the per-passenger charges always reduces frequency.

The effect of an increase in the per-flight charge is clear-cut and negative in sign for both uniform price and frequency:

\[ \frac{dp^T}{d\tau_f} = \frac{1}{\Gamma} \det \begin{pmatrix} \frac{-\partial^2 \pi^T}{\partial p \partial \tau_f} & \frac{\partial^2 \pi^T}{\partial p \partial f} \\ \frac{-\partial^2 \pi^T}{\partial f \partial \tau_f} & \frac{\partial^2 \pi^T}{\partial f^2} \end{pmatrix} \]  
(57a)

\[ = \frac{1}{\Gamma} \det \begin{pmatrix} 0 & \frac{\partial^2 \pi^T}{\partial p \partial f} \\ 1 & \frac{\partial^2 \pi^T}{\partial f^2} \end{pmatrix} < 0 \]  
(57b)

and

\[ \frac{df^T}{d\tau_f} = \frac{1}{\Gamma} \det \begin{pmatrix} \frac{\partial^2 \pi^T}{\partial p^2} & 0 \\ \frac{\partial^2 \pi^T}{\partial p \partial f} & 1 \end{pmatrix} < 0. \]  
(58)
Proposition 3  To establish part (i), consider the first-order condition \( \partial V^T / \partial \tau_q = 0 \), which can be written as

\[
\Delta^T_p D^T - \Delta^T_f c + (p^T (D'_B + D'_L) (\Delta^T_p + \Delta^T_f \hat{\tau} \Gamma')) - \phi D^T \cdot (\Delta^T_p + \Delta^T_f \nu \Gamma') = 0. \tag{59}
\]

Since \( D^T \) is strictly positive in sign, the carrier’s and the social viewpoints can be identical only if the full fares evaluated at average time valuations are minimized conditional on airport cost recovery.

To establish part (ii), suppose that the full fares are minimized at the carrier optimum, which implies \( \Delta^T_f c = -\Delta^T_f \hat{\tau} \Gamma' \). Substituting \(-\Delta^T_f \hat{\tau} \Gamma' \) for \( \Delta^T_f \) in the first-order condition (59) and expanding by \( \Delta^T_f \nu \Gamma' D^T \), yields

\[
(-\hat{\tau} \Gamma' D^T - c) - (p^T (D'_B + D'_L) + D^T) (\nu - \hat{\nu}) \Gamma' = 0. \tag{60}
\]

Suppose that the optimal per-flight charge is negative in sign, while the optimal per-passenger charge is positive in sign. The first term on the LHS is then negative in sign, while the second term is also negative in sign; a contradiction. Suppose instead that the optimal per-flight charge is positive in sign, while the optimal per-passenger charge is negative in sign. In this situation, the first term on the LHS is positive in sign, while the second term is also positive in sign; another contradiction. Finally, suppose that both the optimal per-flight charge and the optimal per-passenger charge are positive in sign. Then, the first term on the LHS is positive in sign, while the second term is negative in sign, which thus establishes the necessary condition for the carrier’s and the socially optimal behavior to be identical.