Analysis on Price-cap Regulation of Congested Airports

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Abstract: This paper investigates price-cap regulation of an airport where airport facility (e.g. runway) is congestible and air carriers may be non-atomistic. We show that when the level of airport congestion is low, the single-till price-cap regulation dominates the dual-till price-cap regulation with respect to social welfare maximization. On the other hand, the dual-till regulation performs better than the single-till regulation when airport congestion is significant. We further derive the formula of the optimal price caps.

Keywords: Price-cap regulation; Airport; Congestion; Single-till; Dual-till; Non-atomistic carriers

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1. Introduction

Airports have traditionally been owned and managed by governments. Starting with the privatization of airports in the UK in the late 1980s, more and more airports have been privatized (or partially privatized) around the world, including Europe, Australia and New Zealand. Asia, South America and Africa are also in the process of privatizing their airports (e.g. Oum et al. 2004; Winston and de Rus 2008). As the ownership of airports changes from public to private, the objective of airports will likely become profit maximization instead of social welfare maximization. Price regulations may thus be called upon so as to contain potential market power of an airport, which is a “local monopoly” candidate (e.g. Fu et al. 2006; Basso 2008).¹

The exact form of price regulation appears to vary both across countries and over time. For example, a number of countries – including Germany and Canada – have adopted cost-based regulation, while price-cap regulation has been popular in countries such as the UK, Denmark, Ireland and Australia. Price-cap regulation adjusts the operator’s prices according to the price-cap index that reflects the overall rate of inflation in the economy, the ability of the operator to gain efficiencies relative to the average firm in the economy, and the inflation in the operator’s input prices relative to the average firm in the economy. Since price-cap regulation gives firms incentives to be cost efficient, it is often referred to as “incentive regulation.” For example, while German airports have traditionally been regulated by cost-based regulation, price-cap regulation has been in place since 2000 for Hamburg airport and a few other airports (Mueller et al. 2010). Niemeier (2002) argues that such a change improves the economic efficiency of airports.

In this paper we focus on an analysis of price-cap regulation of airports. In the case of airports, there are two versions of price-cap regulation: the single-till approach and the dual-till approach. The distinction between the two approaches has to do with the fact that an airport derives revenue from two facets of its business: the traditional aeronautical operation and the commercial (concession) operation. The former refers to aviation activities associated with runways, aircraft parking and terminals, whereas the latter refers to non-aeronautical activities that occur within terminals and on airport land, including terminal concessions (duty-free shops, restaurants, etc.), car rental and car parking. For the last two decades, commercial revenues have grown faster than

¹ On the other hand, as noted in Barbot (2009) and Bel and Fageda (2010), oligopolistic airlines may have market power that can counter the market power of private airports, especially at congested hub airports – as pointed by, e.g., Brueckner (2002), these airports are typically dominated by one, two or three major carriers. In addition, private airports may have incentives to lower aeronautical charges so as to attract more traffic and thereby increase concession revenues (Starkie 2001). The threat of re-regulation can also help mitigate the potential exploitation of market power by private airports (Forsyth 2008).
aeronautical revenues and, as a result, have become the main income source of many airports. Furthermore, commercial operation tends to be more profitable than aeronautical operation (e.g. Jones et al. 1993; Starkie 2001; Francis et al. 2004) owing in part to prevailing regulations and charging mechanisms (e.g. Starkie 2001). Under the single-till price-cap regulation, revenues from both the aeronautical and commercial operations are considered in the determination of price cap on aeronautical charges. By contrast, under the dual-till price-cap approach the aeronautical charges are determined based solely on aeronautical activities.

In this paper, we investigate price-cap regulation of an airport where airport facility (e.g. runway) is congestible and air carriers may be non-atomistic. We show, analytically, that when the level of airport congestion is low, the single-till price-cap regulation dominates the dual-till price-cap regulation with respect to social welfare maximization. On the other hand, the dual-till regulation performs better than the single-till regulation when airport congestion is significant. We further derive the formula of the optimal price caps.

Our paper extends the recent analytical work by Czerny (2006) who shows that the single-till price-cap regulation dominates the dual-till approach with regard to welfare maximization at a non-congestible airport. For the last decade or so, airport congestion and delays have become a major public policy issue, owing mainly to traffic growth having outpaced airport capacity increases, in many countries (e.g. Brueckner 2002; Zhang and Zhang 2006; Basso 2008). A major critique of the single-till approach is that the aeronautical (e.g. runway) charges are set too low at congested airports. When the single-till approach is applied to a capacity-constrained airport, the aeronautical charges must be lowered – as more profits are made from commercial activities – so that the airport remains under the single-till price-cap. Under the single-till price-cap regulation, therefore, the aeronautical charges are lowered at congested airports when economic efficiency requires them to be raised (e.g. Beesley 1999; Starkie 2001; Gillen 2010). It is thus generally believed that the dual-till price-cap regulation is more desirable at a

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2 In a recent study, Van Dender (2007) investigated 55 large US airports from 1998 to 2002, and found that although its share dropped with the slump in travel in 2001 and 2002, concession revenue still represents more than half of the total airport revenue. ATRS (2008) studied 142 airports worldwide and found a majority of these airports derived 40-75% of their revenues from non-aviation services, a major part of which is revenue from concession services (with large hub airports relying, on average, even more on concession income). For earlier studies on the importance of commercial services, see Doganis (1992) and Zhang and Zhang (1997).

3 Czerny (2006) also assumes atomistic airlines at the airport. In our paper, airlines may or may not be atomistic at the airport.
congested airport. Nevertheless, no rigorous theoretical work has shown that the dual-till approach performs better than the single-till approach at congested airports.\(^4\)

The paper is organized as follows. Section 2 sets up the basic model and examines airline competition. Section 3 investigates the airport behavior in choosing aeronautical and concession prices. Section 4 investigates optimal price-cap regulation and compares the single-till regulation with the dual-till regulation, and Section 5 contains the concluding remarks.

2. Model

Consider a model with a single airport and \(n\) competing airlines. Let \(\rho_i\) be the passengers’ perceived “full price” of airline \(i\), where \(i = 1, 2, \ldots, n\). The carriers provide horizontally differentiated outputs and for analytical tractability, we use linear demands:

\[
\rho_i = a - bq_i - \sum_{j \neq i} q_j,
\]

where \(a > 0, b \geq 1\), and \(q_i\) is airline \(i\)’s output (number of passengers). The linear demand functions correspond to a representative consumer’s concave utility function

\[
U(q_1, \ldots, q_n) = a \sum_{i=1}^{n} q_i - \frac{b}{2} \sum_{i=1}^{n} q_i^2 - \sum_{i>j} q_i q_j.
\]

Let \(\tilde{q}_i\) be the number of flights of airline \(i\). Assuming, as is common in the airport pricing literature, that all flights use identical aircraft and have the same load factor (e.g. Brueckner 2002), then each flight has an equal number of passengers. Denoting the number by \(S\), we then have \(\tilde{q}_i = q_i / S\). Letting \(\tilde{Q} = \sum \tilde{q}_i\) and \(Q = \sum q_i\) be, respectively, the number of flights and the number of passengers of all airlines, then \(\tilde{Q} = Q / S\).

\(^4\) While a number of studies have compared the relative merits of single-till and dual-till regulations, there have been only a few theoretical studies on this debate. To the best of our knowledge, Czerny (2006) is the only analytical paper that shows that the single-till price-cap regulation is socially more desirable than the dual-till approach. Although several authors, e.g. Lu and Pagliari (2004), intuitively argue that the single-till price-cap regulation performs better than the dual-till approach at non-congested airports, they do not show the result analytically. Oum et al. (2004) show empirically that the dual-till price-cap regulation provides stronger incentives for capacity investments and cost reductions than no regulation.
Note that the full price $\rho_i$ is the sum of ticket price and congestion cost:

$$\rho_i = p_i + \alpha D(\tilde{Q}, K),$$  

(3)

where $p_i$ is airline $i$'s ticket price, $D$ is the congestion delay time and $\alpha$ denotes the passengers’ value of time. The congestion delay depends on the total number of flights $\tilde{Q}$ and the airport’s (runway) capacity $K$. We shall use the same linear delay function as the one in De Borger and Van Dender (2006) and Basso and Zhang (2007):

$$D(\tilde{Q}, K) = \theta \frac{\tilde{Q}}{K} = \theta \frac{Q}{KS},$$  

(4)

where $\theta$ is a positive parameter. As to be seen later, linear delay function, together with linear demand function, lead to airport profit functions being concave in airport charge, which guarantees price-cap regulation will be binding. Without loss of generality, we normalize $KS = 1$; thus, (3) can be written as

$$p_i = \rho_i - \alpha D(\tilde{Q}, K) = a - bq_i - \sum_{j \neq i} q_j - \alpha \theta Q.$$  

(5)

Next, we specify the passengers’ demand for concessions. Suppose that passengers’ valuation for the commercial product has positive support on the interval $[0,u]$. Let $G(\cdot), g(\cdot)$ be the cumulative distribution function and probability density function of passengers’ valuation, respectively, with a non-decreasing failure rate. That is, $g(x)/\bar{G}(x)$ is non-decreasing in $x$, where $\bar{G}(x) = 1 - G(x)$. Many common distribution functions satisfy this property, including uniform, exponential, truncated Normal, etc. A passenger will consume the concession good if his/her valuation is greater than the concession price $p_c$.

It is worth noting that our treatment of concession demand is different from Oum et al. (2004) and Zhang and Zhang (2010) where the price of concession good is exogenously given and the concession demand is taken simply as a fixed proportion of the aeronautical demand. Our modeling of interaction between aeronautical demand and concession demand is related to, but different from, Czerny (2006). Czerny assumes that (potential) consumers make decisions simultaneously on buying flight ticket and concessions. In other words, he assumes that consumers will buy a flight as long as the joint surplus from consuming the flight and commercial services is positive. However, it is perhaps more reasonable, we believe, to assume that consumers make these two
decisions sequentially: consumers first decide whether to fly. When they are at the airport, they then decide whether to purchase the commercial services provided at the airport.\textsuperscript{5}

The airport regulation is modeled as a three-stage game: in stage 1, the regulator chooses the price-cap on per-passenger aeronautical charge \( p_a \), subject to the airport’s cost recovery constraint. In stage 2, the airport decides both the aeronautical charge (within the given cap) and concession price \( p_c \). In stage 3, each airline chooses its output \( q_i \) to maximize profit (i.e. airlines compete in Cournot fashion). Note that we do not include the concession price in price-cap regulations to reflect the prevailing regulations (e.g. Starkie 2001) – concession prices are generally not regulated in practice.

We solve the subgame perfect equilibrium of the regulatory game through backward induction. More specifically, in stage 3, airline \( i \)’s profit function is

\[
\pi_i = \left[ p_i - c - p_a - \beta D(\hat{Q}, K) \right] q_i ,
\]

(6)

where \( c \) is airlines’ unit operating cost and \( \beta \) denotes their value of time. The first-order condition of (6) is

\[
\frac{d\pi_i}{dq_i} = p_i - c - p_a - \beta \theta Q - q_i (b + \alpha \theta + \beta \theta) = 0 .
\]

(7)

It is easy to see that the second-order condition \( d^2\pi_i / dq_i^2 < 0 \) holds. Imposing symmetry we obtain the Cournot-Nash equilibrium output as:

\[
q_i^* = \frac{a - c - p_a}{(n+1)(\alpha + \beta)\theta + 2b + n - 1} .
\]

(8)

Notice that \( (\alpha + \beta)\theta \) is the total (adjusted) per-passenger value of time taking both the passengers and airlines as a whole. For notational simplicity, we denote it by \( v \).

3. Airport Pricing

Back to stage 2, the airport decides aeronautical charge \( p_a \) and concession price \( p_c \). We first consider, in Section 3.1, the benchmark case of a public welfare-maximizing airport.

\textsuperscript{5} A similar argument was also made in Currier (2008).
This is followed, in Section 3.2, by examination of a private profit-maximizing airport, a more relevant case so far as optimal regulation is concerned.

### 3.1 Welfare-maximizing airport

Consider first a public airport whose objective is to maximize social welfare \( SW \), which is defined as the sum of consumer surplus and producer surplus. Consumer surplus consists of two parts, of which one part is from aeronautical services \( CS_a \), and the other is from concession services \( CS_c \):

\[
CS_a = U(q_1^*, \ldots, q_n^*) - \sum_{i=1}^{n} \rho_i q_i^* = (b + n - 1)q_{i}^{*2} / 2 , \quad (9)
\]

\[
CS_c = \int_{p_c}^{u} Q_c G(x) dx = n q_i^* \int_{p_c}^{u} G(x) dx. \quad (10)
\]

For simplicity, let \( H(p_c) = \tilde{G}(p_c)(p_c - c_c) \) be the per-passenger airport profit from concession operations, and \( I(p_c) = \int_{p_c}^{u} \tilde{G}(x) dx \) be the per-passenger consumer surplus from concession consumption.

Producer surplus is the joint profit of the airport and the \( n \) airlines. Taking the stage-3 airline rivalry into account, the airport’s profit is

\[
\Pi = (p_a - c_a)Q^* + (p_c - c_c)Q^*\tilde{G}(p_c) - F, \quad (11)
\]

where \( Q^* = \sum q_i^* \), \( c_a \) is the airport’s operating cost per passenger, \( c_c \) is the unit cost of the commercial good, and \( F \) is the fixed cost of the airport. To guarantee positive outputs, we must have

\[
a - c - c_a > 0. \quad (12)
\]

From (6) and (9)-(11), it follows that

\[
SW = n q_i^* [a - c - c_a + H(p_c) + I(p_c)] - n q_{i}^{*2} [n v + (b + n - 1) / 2] - F. \quad (13)
\]

Here, the public airport maximizes social welfare by choosing \( p_a \) and \( p_c \) simultaneously. A commonly used method for solving this optimization problem is to show the Hessian matrix being negative definite. We shall take a different approach: We first fix one
variable \( p_a \), and show the objective function is unimodal in another variable \( p_c \). Then we solve the maximizer \( p_c^* \), and plug \( p_c^* \) into the original objective function. With now the objective function having only one variable \( p_a \), we finally solve the single-variable maximization problem.

Notice, in the present case, that \( q_i^* \) does not depend on \( p_c \) and \( a - c - c_a > 0 \) as assumed in (12). Given \( p_a \), therefore, maximizing \( SW \) over \( p_c \) is equivalent to maximizing \( H(p_c) + I(p_c) \) over \( p_c \). With this approach we obtain the following result:

**Proposition 1.** For a public, welfare-maximizing airport, the optimal concession price is \( p_c^w = c_c \), and the optimal aeronautical charge is

\[
p_a^w = c_a + \frac{(a - c - c_a)(n - 1)v - b - I(c_c)(n + 1)v + 2b + n - 1}{2nv + b + n - 1},
\]

where the superscript \( w \) stands for welfare maximization.

**Proof:** We will first show that \( H(p_c) + I(p_c) \) is maximized at \( p_c = c_c \). Taking the first derivative with respect to \( p_c \) yields

\[
\frac{d[H(p_c) + I(p_c)]}{dp_c} = -g(p_c)(p_c - c_c).
\]

Note that (15) is negative when \( p_c > c_c \), and is positive when \( p_c < c_c \). In other words, \( H(p_c) + I(p_c) \) is increasing in \( c_c \) when \( p_c < c_c \), and is decreasing in \( c_c \) when \( p_c > c_c \). Hence, the maximum is achieved at \( p_c^w = c_c \).

Plugging \( p_c^w = c_c \) into (13), we obtain

\[
SW = nq_i^*[a - c - c_a + I(c_c)] - nq_i^{**2}[nv + (b + n - 1)/2] - F.
\]

Taking the first derivative with respect to \( p_a \) yields

\[
\frac{dSW}{dp_a} = -\frac{n[a - c - c_a + I(c_c)]}{(n + 1)v + 2b + n - 1} + \frac{n(2nv + b + n - 1)(a - c - p_a)}{[(n + 1)v + 2b + n - 1]^2}.
\]

Clearly, the second-order condition holds, i.e. \( d^2SW / dp_a^2 < 0 \). Therefore, the optimal aeronautical charge can be derived by setting (17) to zero, and is given in (14). \( Q.E.D. \)
Note that $p_a^w$ in (14) may be written alternatively as

$$p_a^w = c_a - I(c_c) + \left(1 - \frac{1}{n}\right) vQ^* - \frac{1}{n} bQ^*.$$  \hspace{1cm} (18)

Similar to Zhang and Zhang (2010), equation (18) has a clear interpretation: the optimal airport charge is equal to the airport’s unit operating cost, minus concession surplus per passenger, plus a charge for uninternalized congestion, and minus a subsidy to correct airline exploitation of market power. The charge for uninternalized congestion is the “congestion toll” component of the airport charges (Brueckner 2002) whereas the last term in (18) is the “market power” component (Pels and Verhoef 2004).

### 3.2 Profit-maximizing airport

A private airport chooses $p_a$ and $p_c$ to maximize its profit. Analogous to Section 3.1, we first fix one variable $p_a$. Note that given $p_a$, maximizing $\Pi$ over $p_c$ is equivalent to maximizing $H(p_c)$ over $p_c$. The following proposition shows that the optimal concession price chosen by a private airport depends not only on the unit cost $c_c$ but also on the distribution function $G$.

**Proposition 2.** For a private, profit-maximizing airport, there exists a unique optimal concession price, $p_c^\pi > c_c$, which is determined by the following equation (the superscript $\pi$ for profit maximization),

$$\bar{G}(p_c^\pi) - g(p_c^\pi)(p_c^\pi - c_c) = 0.$$  \hspace{1cm} (19)

The privately optimal aeronautical charge is

$$p_a^\pi = c_a + \frac{a - c - c_a - H(p_c^\pi)}{2}.$$  \hspace{1cm} (20)
Proof: We will first show that \( H(p_c) \) has a unique maximizer between \( c_c \) and \( u \). The first-order condition gives

\[
H'(p_c) = \bar{G}(p_c) - g(p_c)(p_c - c_c) = 0.
\]

(21)

It follows that

\[
g(p_c) = \frac{1}{\bar{G}(p_c)}. \quad (22)
\]

The profit-maximizing airport will not choose a concession price \( p_c \) that is less than the unit concession cost \( c_c \). Otherwise, the concession revenue will be negative. So, the right-hand side of (22) is positive and decreasing in \( p_c \). By the assumption of non-decreasing failure rate, the left-hand side of (22) is non-decreasing in \( p_c \). Hence, equation (21) has a unique root. It is easy to check that \( H'(0) = 1 + c_c g(0) > 0 \), and \( H'(u) = -g(u)(u - c_c) < 0 \). Therefore, \( H(p_c) \) is unimodal in \( p_c \), and so \( H(p_c) \) has a unique maximizer between \( c_c \) and \( u \).

Plugging \( p^*_c \) into (11), we obtain

\[
\Pi = (p_a - c_a)Q^* + Q^*H(p^*_c) - F. \quad (23)
\]

Taking the first derivative with respect to \( p_a \) yields

\[
\frac{d\Pi}{dp_a} = \frac{n[a - c + c_a - 2p_a - H(p^*_c)]}{(n+1)v+2b+n-1}. \quad (24)
\]

Clearly, the second-order condition holds, i.e. \( d^2\Pi / dp_a^2 < 0 \). Therefore, the privately optimal aeronautical charge can be derived by setting (24) to zero, and is given in (20). Q.E.D.

Alternatively, we may write \( p^*_a \) in Proposition 2 as

\[
p^*_a = c_a - H(p^*_c) + \left(1 + \frac{1}{n}\right)vQ^* + \left(1 + \frac{2b-1}{n}\right)Q^*. \quad (25)
\]
Thus, the privately optimal airport charge per passenger is equal to the airport’s unit operating cost, minus per-passenger concession profit, plus an overcharge congestion toll, and plus a markup owing to the airport’s monopoly market power. Insights derived from comparing equation (25) with equation (18) are similar to ones in, e.g. Basso (2008).

4. Price-cap Regulation

Having analyzed airline and airport behavior, we now study price-cap regulation on aeronautical charges. A “first best” benchmark is that the regulator maximizes social welfare by setting both the aeronautical charge and concession price, subject to the airport’s cost recovery constraint:

$$\max_{p_a, p_c} SW \quad \text{s.t. } \Pi \geq 0,$$

which leads to Ramsey charges (Czerny 2006). Nevertheless, by the analysis in Section 3 we know that for any given aeronautical charge $p_a$, a profit-maximizing airport will always set concession price at $p_c^\tau$. Thus, by regulating only $p_a$, the best the regulator can achieve is

$$\max_{p_a} SW \quad \text{s.t. } \Pi \geq 0, \quad \text{subject to } p_c = p_c^\tau.$$

We consider (27) as our regulation benchmark, and will solve it in the next section.

4.1 Optimal price-cap

Under price-cap regulation, the optimization problem faced by the profit-maximizing airport is as follows:

$$\max_{p_a, p_c} \Pi \quad \text{s.t. } p_a \leq \bar{p}_a,$$

11
where $\bar{p}_a$ is the price-cap being chosen by the regulator to maximize social welfare subject to the airport’s cost recovery constraint, i.e. the optimal solution of the regulation benchmark.

If we ignore, for the time being, the cost recovery constraint, then the regulation benchmark (27) becomes

$$\begin{align*}
\max_{p_a} & \quad SW \\
\text{s.t.} & \quad p_c = p_c^\pi.
\end{align*}$$

(29)

For given $p_c = p_c^\pi$, the optimal airport charge that a welfare-maximizing regulator will choose is, by (14),

$$p_a^w(p_c^{\pi}) = c_a + \frac{(a-c-c_a)((n-1)v-b)-[H(p_c^{\pi})+I(p_c^{\pi})][(n+1)v+2b+n-1]}{2nv+b+n-1}. \tag{30}$$

Notice that $p_a^w(p_c^{\pi}) < p_c^{\pi}$, which can be easily verified.

Now, we need to check whether (30) satisfies the cost recovery constraint. If

$$\Pi(p_a^w(p_c^{\pi}), p_c^{\pi}) > 0, \tag{31}$$

then $p_a^w(p_c^{\pi})$ is indeed the optimal solution of the regulation benchmark, because the airport’s profit $\Pi$ is concave in $p_a$ and $p_a^w(p_c^{\pi}) < p_c^{\pi}$. If, on the other hand,

$$\Pi(p_a^w(p_c^{\pi}), p_c^{\pi}) < 0, \tag{32}$$

then it is optimal to set price-cap at $p_a^{\pi}$, where the superscript $s$ represents single-till price-cap regulation, and $p_a^{s}$ is the smallest root of

$$\Pi(p_a, p_c^{\pi}) = 0. \tag{33}$$

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$^6$ In the present paper, we follow the common definition of the single-till and dual-till price-cap regulation in the literature, e.g. Oum et al. (2004), Czerny (2006), and Zhang and Zhang (2010). To guarantee that the price-cap regulation will be binding, we let the smallest root be the price-cap. This definition might be considered as a “strict” interpretation of price-cap regulation, and we discuss the issue further in the concluding remarks.
It follows that
\[
p^s_a = c_a + \left( a - c - c_a - H(p^s_c) - \sqrt{(a - c - c_a + H(p^s_c))^2 - 4F[(n + 1)v + 2b + n - 1]/n} \right)/2 .
\]

In other words, the single-till price-cap is optimal when \( \Pi(p^w_a(p^s_c), p^s_c) < 0 \).

Notice that \( \Pi(p^w_a(p^s_c), p^s_c) \) is a quadratic function of \( v \). If \( \Pi(p^w_a(p^s_c), p^s_c) > 0 \) has no solution, then it is optimal for the regulator to set price-cap at \( p^s_a \), i.e. the single-till price-cap is socially optimal. The more interesting case arises, however, when \( \Pi(p^w_a(p^s_c), p^s_c) > 0 \) has solutions; the results are given in Proposition 3.

**Proposition 3.** From the perspective of social welfare maximization,

(i) if \( v > v_2 \) (the value of time is high) or \( v < v_1 \) (the value of time is low), then it is optimal for the regulator to set price-cap at \( p^s_a \), where the critical values \( v_1 \) and \( v_2 \) are the roots of \( \Pi(p^w_a(p^s_c), p^s_c) \) (given by (36) below);

(ii) if \( v_1 < v < v_2 \) (the value of time is moderate), it is optimal for the regulator to set price-cap at \( p^w_a(p^s_c) \) given by (30).

**Proof:** Note that \( \Pi(p^w_a(p^s_c), p^s_c) > 0 \) is equivalent to

\[
A_1 v^2 + A_2 v + A_3 < 0 , \quad \text{where} \quad (35)
\]

\[
A_1 = 4n^2F,
A_2 = 4n[(b + n - 1) - n(a - c - c_a + H(p^s_c) + I(p^s_c))]\left[(n - 1)(a - c - c_a + H(p^s_c)) - (n + 1)I(p^s_c)\right],
A_3 = F[(b + n - 1)^2 + n(a - c - c_a + H(p^s_c) + I(p^s_c))][b(a - c - c_a + H(p^s_c)) + (2b + n - 1)I(p^s_c)]
\]

Note that \( A_1 > 0 \) and \( A_3 > 0 \). The value of time must be positive (\( v > 0 \)), so (35) has solution if and only if \( A_2^2 - 4A_1A_3 > 0 \) and \( A_2 < 0 \). In particular, with a monopolist carrier (\( n = 1 \)), \( A_2 \geq 0 \), and so (35) has no solution, which implies that \( p^w_a(p^s_c) < p^s_a \). In other words, with a monopolist carrier and the airport’s cost recovery constraint, it is always optimal for the regulator to set price-cap at \( p^s_a \). Thereafter, we assume \( A_2^2 - 4A_1A_3 > 0 \) and \( A_2 < 0 \). Then the solution of (35) is

\[
v_1 < v < v_2 , \quad \text{where}
\]
Therefore, it is optimal for the regulator to set price-cap at \( p_a^* \) when \( v < v_1 \); while it is optimal for the regulator to set price-cap at \( p_a^*(p_c^*) \) when \( v_1 < v < v_2 \). \( Q.E.D. \)

When the value of time is either high or low, social welfare can be further increased by setting price-cap below the single-till price-cap \( p_a^* \). However, the airport’s profit will be negative. Therefore, with the airport’s cost recovery constraint, it is optimal for the regulator to set price-cap at \( p_a^* \). When the value of time is intermediate, we have \( p_a^* \leq p_a^w(p_c^*) \leq p_a^* \). Note that social welfare is concave in the airport charge, it is optimal for the regulator to set price-cap at \( p_a^w(p_c^*) \). The airport makes positive profit in this case.

### 4.2 Single-till vs. dual-till regulations

Given the on-going debate on single-till vs. dual-till price-cap regulations, it is worthwhile to compare these two approaches. First, we need to introduce the dual-till price-cap regulation. Following Czerny (2006), we rewrite the airport’s profit as

\[
\Pi = \Pi_a + \Pi_c, \tag{37}
\]

where \( \Pi_a = (p_a - c_a)Q^* - \lambda F \) and \( \Pi_c = Q^*H(p_c) - (1-\lambda)F \) are the aeronautical profit and the commercial profit, respectively. The fixed cost of the airport is \( F \), of which a fraction \( \lambda \in (0,1) \) is attributed to aeronautical services, with the remaining fraction to concession activities.

Under the dual-till price-cap regulation, \( \bar{p}_a = p_a^d \), where the superscript \( d \) represents dual-till price-cap regulation and \( p_a^d \) is the smallest root of \( \Pi_a(p_a) = 0 \). Solving \( \Pi_a(p_a) = 0 \) yields

\[
p_a^d = c_a + \frac{a - c - c_a - \sqrt{(a - c - c_a)^2 - 4\lambda F[(n+1)v + 2b + n - 1]/n}}{2}. \tag{38}
\]
It is reasonable to assume that a private profit-maximizing airport without regulation makes positive profit from the aeronautical services, i.e. \( \Pi_a(p_a^\pi) > 0 \), which implies \( \nu < \nu_3 \), with

\[
\nu_3 = \frac{n \left[ (a-c-c_a)^2 - H^2(p_c^\pi) \right]}{4(n+1)\lambda F} - \frac{2b+n-1}{n+1}.
\] (39)

Otherwise, price-cap regulation is unnecessary. Condition (39) says that the value of time cannot be too high. Note that \( \Pi_a(p_a) \) is concave, and \( p_a^d \) is the smallest root of \( \Pi_a(p_a) = 0 \), so we must have \( p_a^d < p_a^\pi \). In order to make sure that under the dual-till price-cap regulation, the private profit-maximizing airport makes positive profit from concession activities, we assume that \( \Pi_c(p_a^d, p_c^\pi) > 0 \). Otherwise, the private airport will not provide concession services. The positive concession profit implies \( \nu < \nu_4 \), with

\[
\nu_4 = \frac{nH(p_c^\pi) \left[ a-c-c_a + H(p_c^\pi) \right]}{2(n+1)(1-\lambda)F} - \frac{2b+n-1}{n+1}.
\] (40)

Thereafter, we assume

\[ \nu < \min\{\nu_3, \nu_4\}. \] (41)

Note that for the model to be meaningful, we must have \( \min\{\nu_3, \nu_4\} > 0 \).

Notice that

\[
\Pi(p_a^d, p_c^\pi) = \Pi_a(p_a^d) + \Pi_c(p_a^d, p_c^\pi) = \Pi_c(p_a^d, p_c^\pi) > 0 = \Pi(p_a^d, p_c^\pi).
\] (42)

Since \( \Pi(p_a, p_c^\pi) \) is concave, and both \( p_a^\pi \) and \( p_a^d \) are less than \( p_a^\pi \), it follows that

\[ p_a^\pi < p_a^d < p_a^\pi. \] (43)

Now, we are ready to compare single-till and dual-till price-cap regulations. As shown above, when \( \Pi(p_a^w(p_c^\pi), p_c^\pi) < 0 \), the single-till price-cap regulation is optimal, and so dominates the dual-till price-cap regulation. Suppose now that \( \Pi(p_a^w(p_c^\pi), p_c^\pi) > 0 \). If the aeronautical profit \( \Pi_a(p_a^w(p_c^\pi)) > 0 \), then we have \( p_a^w(p_c^\pi) < p_a^w < p_a^d(p_c^\pi) \). Hence, from the perspective of welfare maximization, the dual-till regulation is better than the single-till regulation. If the aeronautical profit \( \Pi_a(p_a^w(p_c^\pi)) < 0 \), then \( p_a^w(p_c^\pi) < p_a^w < p_a^d \), then we need to compare \( SW(p_a^w, p_c^\pi) \) and \( SW(p_a^d, p_c^\pi) \).
Notice that \( \Pi_a(p^w_a(p^\pi_c)) \) is also a quadratic function of \( v \). Again we will focus on the case when \( \Pi_a(p^w_a(p^\pi_c)) > 0 \) has solutions, and the results are given in Proposition 4.

**Proposition 4.** From the perspective of social welfare maximization,

(i) if \( v > v_2 \) (the value of time is high) or \( v < v_1 \) (the value of time is low), then the single-till price-cap regulation dominates the dual-till price-cap regulation, where the critical values \( v_1 \) and \( v_2 \) are the roots of \( \Pi(p^w_a(p^\pi_c), p^\pi_c) \);

(ii) if \( v_5 < v < v_6 \) (the value of time is moderate), the dual-till price-cap regulation performs better than the single-till price-cap regulation, where the critical values \( v_5 \) and \( v_6 \) are the roots of \( \Pi_a(p^w_a(p^\pi_c)) \).

**Proof:** Proposition 4(i) follows immediately from Proposition 3(i). We will next show Proposition 4(ii). Analogous to the proof of Proposition 3, \( \Pi_a(p^w_a(p^\pi_c)) > 0 \) is equivalent to

\[
A_4v^2 + A_5v + A_6 < 0, \text{ where}\]

\[
A_4 = 4\lambda n^2 F, \]

\[
A_5 = 4\lambda nF(b + n - 1) - n[a - c - c_a + H(p^\pi_c) + I(p^\pi_c)][(n - 1)(a - c - c_a) - (n + 1)(H(p^\pi_c) + I(p^\pi_c))], \]

\[
A_6 = \lambda F(b + n - 1)^2 + n[a - c - c_a + H(p^\pi_c) + I(p^\pi_c)][b(a - c - c_a) + (2b + n - 1)(H(p^\pi_c) + I(p^\pi_c))]. \]

Similar to the proof of Proposition 3, we assume \( A_5^2 - 4A_4A_6 > 0 \) and \( A_5 < 0 \). Then the solution of (44) is

\[
v_5 < v < v_6, \text{ where} \]

\[
v_5 = \frac{-A_5 - \sqrt{A_5^2 - 4A_4A_6}}{2A_4} > 0, \text{ and } v_6 = \frac{-A_5 + \sqrt{A_5^2 - 4A_4A_6}}{2A_4} > 0. \quad (45)\]

Since the private profit-maximizing airport makes positive profit from concession activities, \( \Pi_a(p^w_a(p^\pi_c)) > 0 \) implies that \( \Pi(p^w_a(p^\pi_c), p^\pi_c) > 0 \), and so \( v_1 < v_5 < v_6 < v_2 \) given that condition (41) holds. Therefore, the single-till price-cap regulation dominates the dual-till price-cap regulation when \( v > v_2 \) or \( v < v_1 \); while the dual-till price-cap regulation performs better than the single-till price-cap regulation when \( v_3 < v < v_6 \).

Q.E.D.
When the value of time is high ($v > v_1$), the level of airport congestion will be low. The number of passengers will be too low with respect to social welfare maximization. By lowering airport charge, the regulator induces airlines to lower ticket prices, and thus attract more passengers. Since $p_a^s < p_a^d$, then the single-till price-cap regulation outperforms the dual-till price-cap regulation.

Recall that $v = (\alpha + \beta)\theta$ is the (adjusted) value of time taking both passengers and airlines as a whole. When the value of time is low ($v < v_1$), the parameter $\theta$ will be small given the empirical evidence that the value of time of passengers and airlines, $(\alpha + \beta)$, is significantly positive (Morrison and Winston 1989; Morrison 1987; and Hess et al. 2007). With a small $\theta$, the congestion delays will by (4) be small as well. Consequently, the airport congestion level is low from the perspective of passengers and airlines. Hence, social welfare can be improved by having more passengers and flights, which can be achieved by lowering airport charge.

It is worth pointing out that “no congestion” is a limiting case of Proposition 4(ii). More specifically, when the value of time is either extremely high ($v \to \infty$) or extremely low ($v \to 0$), the level of airport congestion will be negligible. Our result for the limiting case is consistent with Czerny (2006): at a non-congested airport, the single-till approach dominates the dual-till approach with regard to welfare maximization.

Furthermore, when the value of time is intermediate ($v_5 < v < v_6$), the airport congestion delays become a significant issue, such that social welfare can be improved by reducing airport congestion. By allowing a higher airport charge, the regulator induces airlines to increase ticket prices, thereby reducing airport congestion. Given that $p_a^s < p_a^d$, the dual-till price-cap regulation dominates the single-till price-cap regulation from the perspective of welfare maximization.

Proposition 4 deals with the case that the aeronautical profit $\Pi_a(p_a^w(p^r_c)) > 0$. We need to solve the case with $\Pi_a(p_a^w(p^r_c)) < 0$. Intuitively, there should exist some critical values $v_7 \in (v_1, v_5)$ and $v_8 \in (v_6, v_2)$ such that the single-till approach performs better than the dual-till approach when $v_1 < v < v_7$, or $v_8 < v < v_2$, while the dual-till scheme is better when $v_7 < v < v_8$, or $v_6 < v < v_8$. The situation is illustrated in Figure 1. However, we are not able to establish the result analytically. We turn to numerical analysis as a result. In particular, we adopt the parameter values from Basso (2008) with some minor adjustments. The parameter values are given in Table 1.
The numerical analysis (results shown in Table 2) confirms that with a monopolist carrier, the single-till price-cap regulation is optimal under the airport’s cost recovery constraint. Furthermore, when \( \lambda = 0.98 \), i.e. 98% of the airport’s fixed cost is attributed to aeronautical services, \( v_2 < \min \{ v_3, v_4 \} \) always holds. As expected, we have \( v_1 < v_3 < v_6 < v_2 \), and so all the critical values are meaningful. For example, with two competing airlines, we must have the value of time \( v < \min \{ v_3, v_4 \} = 43.292 \) for the model to be meaningful. By Proposition 4, the single-till price-cap regulation dominates the dual-till price-cap regulation when \( v > v_2 = 30.242 \), or \( v < v_1 = 1.719 \); while the dual-till approach outperforms the single-till approach when \( 1.861 = v_5 < v < v_6 = 29.073 \). However, Proposition 4 does not cover the cases when

\[
1.719 = v_1 < v < v_5 = 1.861, \text{ and } 29.073 = v_6 < v < v_2 = 30.242.
\] (46)

Now we numerically observe that there exist some critical values \( v_7 \) and \( v_8 \) such that the single-till scheme outperforms the dual-till scheme when

\[
1.719 = v_1 < v < v_7 = 1.788, \text{ and } 29.666 = v_8 < v < v_2 = 30.242;
\] (47)

while the dual-till scheme is better than the single-till scheme when

\[
1.788 = v_7 < v < v_5 = 1.861, \text{ and } 29.073 = v_6 < v < v_8 = 29.666.
\] (48)

In summary, the dual-till scheme performs better when

\[
1.788 = v_7 < v < v_8 = 29.666;
\] (49)

whereas the single-till scheme performs better when

\[
v < v_7 = 1.788, \text{ or } v_8 = 29.666 < v < \min \{ v_3, v_4 \} = 43.292.
\] (50)
When $\lambda = 0.8$, i.e. 80% of the airport’s fixed cost is attributed to aeronautical services, $v_2 < \min \{v_3, v_4\}$ does not hold. Recall that we require $v < \min \{v_3, v_4\}$. Because in this case, $v_2, v_6,$ and $v_8$ are greater than $\min \{v_3, v_4\}$, they are meaningless. For example, with two competing airlines, we must have the value of time $v < \min \{v_3, v_4\} = 4.203$ for the model to be meaningful. By Proposition 4, the single-till price-cap regulation dominates the dual-till price-cap regulation when $v < v_1 = 1.719$; while the dual-till approach outperforms the single-till approach when $v > v_5 = 1.821$. However, Proposition 4 does not cover the case when

$$1.719 = v_1 < v < v_5 = 1.821.$$  

(51)

Now we numerically observe that there exists some critical values $v_7$ such that the single-till scheme performs better than the dual-till scheme when

$$1.719 = v_1 < v < v_7 = 1.769;$$  

(52)

while the dual-till scheme is better than the single-till scheme when

$$1.769 = v_7 < v < v_5 = 1.821.$$  

(53)

In summary, the dual-till scheme performs better when

$$1.769 = v_7 < v < \min \{v_3, v_4\} = 4.203;$$  

(54)

whereas the single-till scheme performs better when

$$v < v_7 = 1.769.$$  

(55)

5. Concluding Remarks

In this paper, we have studied price-cap regulation of airports with airport congestion. We found that when the level of airport congestion is low, the single-till price-cap
regulation dominates the dual-till price-cap regulation with respect to welfare maximization. This result is consistent with Czerny (2006)’s result for non-congested airports (i.e. congestion level is zero), although our model setup is very different from his. More importantly, we showed that when airport congestion is significant, the dual-till scheme performs better than the single-till scheme. Our result thus provides analytical support for the “common belief” – that the dual-till price-cap regulation should be preferred over the single-till price-cap regulation at congested airports – which has appeared in several descriptive studies. We believe that we are the first authors to show this intuitive result analytically.

The paper has also raised several issues and avenues for future research. First, we have assumed that the airport capacity is fixed. Incorporating airport capacity as a decision variable is an important direction for future research. Second, we focus on a static model. In practice, price-cap regulations on airport charges are usually adjusted every (say) five years. It is practically relevant to explore the dynamic nature of price-cap regulations. Third, following the literature on price-cap regulation, we have adopted the “strict” interpretation of the single-till and dual-till price-cap regulation. Alternatively, one might introduce a more “flexible” interpretation of the single-till and dual-till price-cap regulation. Specifically, define the flexible single-till (dual-till, respectively) price-cap as the maximum of the welfare-maximizing airport charge and the strict single-till (dual-till, respectively) price-cap. Given these interpretations, it would be interesting to compare the performance of the flexible single-till and dual-till schemes.

Finally, a number of airports are contemplating to switch from their existing rate-of-return (ROR) regulation to the price-cap regulation. Under ROR regulation, the regulated firm is allowed to charge the price that would prevail in a competitive market, which is equal to efficient costs of production plus a market-determined rate of return on capital. A major limitation of the ROR approach is the well-known Averch-Johnson effect: i.e. if the allowable ROR is set too high, the regulated firm can increase its profit by enhancing capital assets, thus firms have a consequent tendency to over-invest (Averch and Johnson 1962). Concerns also exist regarding productive inefficiency: in
particular, the cost-based nature of ROR regulation suggests that airports would not benefit from cost reduction. While recent empirical studies by Bel and Fageda (2010) and Bilotkach et al. (2010) find no significant difference between these two types of regulations in terms of airport charges, it is important to compare the two analytically in terms of prices, profits and social welfare.

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**Figure 1: Single-till price-cap regulation vs. dual-till price-cap regulation**

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**Table 1: Parameter values for numerical analysis**

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<td>Airlines</td>
<td>$c = 360,\ \text{airlines' operating cost per passenger}$</td>
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<td>$n = 1, 2, 5, 10,\ \text{number of airlines}$</td>
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<td>Airport</td>
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<td>$F = 10000,\ \text{airport's fixed cost}$</td>
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<td></td>
<td>$\lambda = 0.98, 0.8,\ \text{fraction of airport's fixed cost due to aeronautical services}$</td>
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<td></td>
<td>$c_c = 10,\ \text{unit cost of the commercial product}$</td>
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<td>Passengers</td>
<td>Valuation of the commercial product is assumed to be uniformly distributed on the interval $[0, u]$, where $u = 100$.</td>
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Source: Basso (2008) with some minor adjustments by the authors.
Table 2: Results of numerical analysis

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