Airport Congestion Pricing and its Welfare Implications:  
The Variable Passenger Time Cost Case  

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Abstract: This paper develops an analytical framework for airport congestion pricing by considering variable passenger time costs. We find that first, congestion delays may not be fully internalized at the carrier level under different market structures, including those airports dominated by a monopoly airline. Thus, congestion pricing is always necessary regardless of the market structures. Second, although congestion pricing could be welfare-improving, it may not be Pareto-improving. This may explain why congestion pricing is unpopular in the real world. Finally, changes in passengers’ welfare after imposing congestion pricing depend on their time valuation. To illustrate our analytical results, numerical simulation is also conducted.  

JEL classification: L93, H23, L50  

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1. Introduction

During the last several years, airlines and passengers have been suffering from congestion at busy airports, and airport delays have become a major public policy issue. Since the early work of Levine (1969), Carlin and Park (1970), and Borins (1978), economists have approached airport congestion by calling for the use of a price mechanism, under which landing fees are based on an aircraft’s contribution to congestion (see Basso and Zhang, 2007a, for a comprehensive review). In particular, the intra-day utilization of airport facilities varies, and the congestion levels are different in different periods of a day. As a result, the airport ‘peak load’ congestion pricing mechanism is proposed, which involves charging different landing fees at different times: during peak hours, flights are charged higher rates than during off-peak hours. The congestion pricing is desirable from an efficiency point of view, because social marginal cost varies depending on the time the runway and slots are used, and so the pricing better reflects this varied marginal cost than a flat fee structure. A vast literature considered the peak-load pricing at the airport level has been developed (e.g., Morrison, 1983; Morrison and Winston, 1989; Oum and Zhang, 1990; Arnott, De Palma and Lindsey, 1993; Daniel, 1995, 2001), while Brueckner (2002, 2005), and Basso and Zhang (2007b) further investigated the peak-load pricing at both the airport and airline levels.

1 Landing fee is the main component of airport pricing. At Hong Kong International Airport (HKIA), for instance, the airport charges consist of three components: landing, aircraft parking, and terminal building charges (TBC). Landing fees are based on aircraft movements, while TBCs are passenger-based. In a ‘typical’ case (a B747 with 418 seats, 66.8% load factor and 4-hour turnover) it has been calculated that the landing fee accounts for 68.7% of the total charge, parking 6.6% and TBC 24.7%.

2 A less mentioned benefit of congestion pricing is that it may facilitate airlines’ entry onto routes from congested airports. Dresner, Windle and Yao (2002) find that among the airport barriers they analyzed, gate utilization during peak periods is the most significant deterrent to entry in the U.S. airline industry.
The first objective of this paper is to consider variable passenger time costs in the airport congestion pricing analysis. A common assumption made in the literature is that all passengers’ value of travel time saving (VTTS) – the monetary value attached to saving an amount of travel time – is identical. In other words, for a given number of flights, time costs due to congestion delays resulting from traveling in a congested period are the same for all travelers. This assumption may be unrealistic. For instance, business passengers’ VTTS would be higher than that for their leisure counterparts. This observation is supported by empirical literature on the air travelers’ VTTS estimation, which indicates that their VTTS depends on, for example, their travel purposes and wage rates. In particular, Hess, Adler and Polak (2007) find that business and leisure travelers’ willingness-to-pay (WTP) for on-time performance are $10.39 and $7.02, respectively.

In addition, von Wartburg and Waters (2004) contain a detailed discussion on the relationship between the VTTS and income. Their comprehensive survey of the relevant studies (e.g., MVA Consultancy, et al., 1987; AHGC, 1999; Gunn, et al., 1999; Wardman, 2001; Mackie, et al., 2001) suggests that the income elasticity of VTTS is positive. As is to be shown below, considering the heterogeneity in passenger time cost may have a significant implication on optimal airport congestion pricing and its welfare-redistributive issues.

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3 Daniel (2001) considers the case that airlines are heterogeneous in time layover and queuing time values, while consumers’ heterogeneity in time value is not taken into account. In addition, De Palma and Lindsey (2004) examine road congestion pricing with travelers’ heterogeneity in wages, values of travel time, and the congestion characteristics of their vehicles. In the analysis, they consider atomistic road users. As a consequence, the congestion internalization by non-atomistic carriers – one of the major issues we want to address – is not examined.

4 The WTP for the probability of on-time flights increased by 10%.
Second, an important debate in the airport congestion literature is whether airlines internalize their self-imposed congestion. The debate is practically important as it affects the magnitude of optimal airport congestion pricing, and also suggests whether the pricing is necessary at airports dominated by a few airlines. Empirical results in Daniel (1995), and Daniel and Harback (2007) suggest that an atomistic model, in which carriers do not internalize any congestion, fits the data better, while Brueckner (2002) and Mayer and Sinai (2003) find empirical evidence to support the self-internalization hypothesis. To explain the two contrary hypotheses, analytical models assuming carriers competing in Cournot fashion (e.g., Brueckner, 2002; Pels and Verhoef, 2004; Zhang and Zhang, 2006; Basso, 2007) have been developed to explain the self-internalization hypothesis, while Daniel (1995) argues that Stackelberg/fringe competition will lead to the non-internalization result. Brueckner and van Dender (2007) provide a unified framework for the two arguments. Different from the literature, this paper will explore a case that incomplete self-internalization would occur even if carriers are assumed to be competing in Cournot fashion.

Third, although it is argued by economists that airport congestion pricing could be socially optimal, it has not really been implemented at airports worldwide. This paper also aims to suggest a potential explanation for the unpopularity of congestion pricing in practice. Note that due to its importance to economies and its market characteristics (namely, to a certain extent, being a natural monopoly), most airports are regulated by

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5 Fung, Law and Ng (2006) find that the total benefit brought by the aviation industry was 7.02 percent of the Hong Kong’s GDP at factor cost (at current prices) in 2003; The aviation industry in UK directly employed 186,000 people (full-time equivalents) in 2004, and helped to support over 520,000 jobs in total
the governments or outright publicly owned.\textsuperscript{6} Airport operating decisions, including its pricing, can be politically sensitive, and the welfare-redistributive issue plays an important role in the decision-making process.\textsuperscript{7} In his simulation model, Daniel (2001) discusses the re-distributive issue and evaluates several price-and-rebate programs, some of which are self-financing and Pareto-improving. However an effective re-distributive mechanism is usually not in place.\textsuperscript{8} To shed some light on the issue, we will discuss the re-distributive impact of congestion tolls taking variable passenger time costs into account.

The analytical model in this paper extends the framework in Brueckner (2002) by incorporating variable passenger time costs into the analysis, a case that was briefly discussed by Brueckner. We find that congestion costs may not be fully internalized under different market structures if variable passenger time costs are taken into account for two reasons. First, as also discussed in the literature, each oligopoly airline at an airport only internalizes the congestion one of its flights imposing on its other flights but not that on other airlines’ flights. Second, time costs of passengers with high travel benefits (for example, business travelers) are not fully reflected in the carriers’ pricing, as the carriers only concern about inframarginal passengers, who are indifferent to travel in the peak and off-peak periods, in their profit maximization. Given our result, a social

\textsuperscript{6} World Bank (2003) notes that due to the “natural monopoly” characteristics of some airport services, governments developed regulatory policies for airport systems.

\textsuperscript{7} For example, the Canadian Airport Authorities are required to give not less than 60 days advance public notice in local news media for all changes in user charges (excluding rent), together with an explanation for the noted increase.
welfare-maximizing airport should thus impose a positive congestion toll under different market structures to induce full internalization of congestion at the carrier level. In the welfare analysis, we find that if a positive congestion toll is imposed, some passengers who have a high valuation of time costs may be better-off in the variable time cost case, while all passengers will not be better-off in the constant time cost case. Nevertheless, our simulation results show that carriers and passengers would be worse-off after the imposition of the congestion pricing. This non-Pareto-improving result may explain why the airport congestion pricing appears unpopular in practice.

The paper is organized as follows. Section 2 discusses the airport congestion and delay in Asia Pacific. Section 3 sets up the model. Sections 4 and 5 consider carrier competition and airport pricing, respectively. Section 6 discusses the welfare implications of the congestion pricing on airport, air carriers and passengers. Numerical simulation is conducted in Section 7, and Section 8 concludes.

2. Airport Congestion and Delay in Asia Pacific

Although the problem of airport congestion and delay has been studied extensively in other parts of the world (e.g., Brueckner, 2002; Mayer and Sinai, 2003, for US; and Reynolds-Feighan and Button, 1999; Santos and Robin, 2007, for Europe), we are not aware of any published studies on the problem for the Asia-Pacific region. The aviation

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8 In Japan, local residents are subsidized by the Narita Airport for aviation noise. Yet there is no similar redistributive mechanism for congestion delays at the airport level in practice. Instead, since 2003, the CAAC has required Chinese airlines to compensate their passengers for flight delays.
market in Asia Pacific has witnessed a substantial growth in the last few decades due to the rapid economic growth and airline liberalization in the region. This fast-growing air transport demand has imposed great pressures on the existing airport capacity, and has led to congestion at major airports in the region. For instance, in China, passenger terminals operated, on average, 15% above their capacities, whereas cargo terminals and facilities could only handle 65% of potential demand throughout most of the 1990s (Zhang and Chen, 2003). Table 1 shows that in September 2007, the percentage of flight delays in China was 17.5%, increased by 1.9% comparing with that in the same period of 2006. The congestion problem is particularly severe at some major Chinese airports. For example, due to increasing congestion and delays, in 2007 the Civil Aviation Administration of China (CAAC) – the country’s industry regulator – imposed daily ceilings of landings/taking-offs not exceeding 1,100 and 650 flights at Beijing Capital International Airport and Shanghai Pudong International Airport – the country’s two busiest airports – respectively.

[Table 1]

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9 The figure seems to be slightly less than that in US, where the percentage of flight delays was 18.3% in the same period. Yet it should be noted that the definition of the on-time flight is different in the two countries. In US, a flight is counted as on-time if it operated (left from or arrived at the gate) less than 15 minutes later the scheduled time shown in the carriers’ Computerized Reservations Systems. On the other hand, in China, a flight is considered as on-time if the boarding gate was closed at the scheduled time, and then the flight took off within 25 minutes for airports at Beijing, Shanghai and Guangzhou, and within 15 minutes for other airports.

10 Source: CAAC and Bureau of Transportation Statistics, US DOT, websites.
In the southern China’s Pearl River Delta which includes Hong Kong and Macau, the airspace congestion has led to increasing delays. It is reported that 2,996 flights departing from Hong Kong were delayed in the first ten months of 2006, comparing with the 973 and 1,733 delayed flights in 2004 and 2005 respectively, and 69.7% of flights from/to Macau were delayed in May 2006 (Zhang and Yuen, 2007). In Bangkok, the Thai government was required to reopen its old airport in March 2007 to ease air traffic congestion at the new airport which just began in operation in 2006. Congestion is perhaps even more acute at some of the major Japanese airports.

Furthermore, the region is expected to experience a rapid growth, at 5.8% per annum through 2025, and to become the largest aviation market in the world in terms of both passenger and freight traffic (ICAO, 2007). As a consequence, more airports in the region may experience congestion, while the situation is expected to get worse at those currently congested airports if no suitable measures are taken. For example, Figures 1a and 1b show the flight patterns at the Hong Kong International Airport (HKIA) in 2007 and 2020 (estimated), respectively. The figures show that while the airport is currently operated under its capacity, the existing capacity would not meet the demand in 2020.

[Figure 1a]

[Figure 1b]
Although airport expansion has been the major solution for dealing with the congestion problem in Asia Pacific,\textsuperscript{11} it may not be sustainable in the future for several reasons. First, along with economic development, people are more aware of environmental issues (e.g., noise and air pollution concerns), and are also more organized in protecting their own interests.\textsuperscript{12} Thus, airport expansion plans may face a strong opposition from local residents. For example, because of its local residents’ opposition due to aviation noise and land expropriation, the expansion of Japan’s Narita Airport has been limited. Second, congestion is not only experienced at airport facilities, but at airspace as well. In the Hong Kong example mentioned above, one of the major concerns for building the third runway at HKIA has been whether airspace congestion in the Pearl River Delta can be resolved.\textsuperscript{13}

Finally, airport expansion usually involves a huge capital investment and is time-consuming,\textsuperscript{14} whereas the demand in the future is highly uncertain. As a result, airport expansion should not be considered as the only solution to ease airport congestion in the

\textsuperscript{11} The CAAC commenced construction on 35 new airports in 2004, in which 33 of them are regional facilities, and the Centre for Asia Pacific Aviation estimates that China will have 240 commercial airports by 2010. The Centre estimates further that the capital needed to meet that infrastructure requirement will top 10 billion yuan (US$1.3 billion) a year (Air Transport World, February 2006, p.32).

\textsuperscript{12} In the environmental economics literature, the Environmental Kuznets Curve (EKC) hypothesis, which predicts pollution rises with income as long as income is relatively low and declines once income has exceeded a threshold level, is empirically supported in many studies (for example, Hettige, Lucas and Wheeler, 1992; Grossman and Krueger, 1993, 1995; Selden and Song, 1994). One of the explanations for the downward-sloping part of EKC is that when income increases, households choose more environmental quality through public action (McConnell, 1997). Note that the per capita Gross Domestic Product (GDP) of many Asian cities (for example, in 2006, the per capita GDP of Guangzhou and Shanghai were US$11,000 and US$7,200, respectively) is closed to or above the threshold (per capita GDP US$8,000 found by Grossman and Krueger (1995)).

\textsuperscript{13} Philip Chen Nan-lok, the Chief Executive of Cathay Pacific, argued that a third runway would not alleviate the insufficient time slots at the Hong Kong airport if the problem of limited airspace is not cleared up first (“Third runway will not ease crowding,” 18\textsuperscript{th} January 2007, South China Morning Post).

\textsuperscript{14} Peter, Lok Kung-nam, the former director of the Hong Kong Civil Aviation Department, estimated that the required investment of the proposed third runway at the Hong Kong airport could be up to HK$30 billion (US$3.8 billion) (16\textsuperscript{th} January 2007, Ta Kung Pao).
region, and other possible complementary solutions need to be explored. Here airport congestion pricing may be one of the most feasible and easiest solutions to deal with the problem.\textsuperscript{15} Thus, airport congestion pricing analysis is practically relevant to the aviation market in the region; it may also provide a better guidance for airports in the region to set an appropriate level of congestion tolls and help gain political support.

3. Model

We consider a three-stage model of airport and airline behavior, in which \( N \) air carriers are in service at a congested airport.\textsuperscript{16} In the first stage, the airport decides its airport charges on the carriers in the peak and off-peak periods, and in the second stage each carrier chooses its output in terms of the number of flights in the two periods. Finally, consumers choose between three mutually exclusive alternatives, namely peak period travel; off-peak period travel; and no travel.

Passengers are represented by a continuum with index \( \theta \), which is uniformly distributed between 0 and \( \Phi \) with a unit density. Travel benefits depend on \( \theta \) and the travel periods. The benefits from off-peak travel are given by the function \( b_o(\theta) \), which is independent of \( n_o \), which denotes the number of flights in the off-peak period, as no

\textsuperscript{15} Another way to relieve airport congestion is by slot control. As argued by Czerny (2007), without uncertainty, the use of congestion pricing is equivalent to slot control. Thus the congestion pricing analysis, as in this paper, can also shed some light on the use of slot control in practice.

\textsuperscript{16} For simplicity, this paper, as in Brueckner (2002), focuses on a single-airport case. As a consequence, the system-wide effects of congestion pricing in a network of airports (see Brueckner, 2005; Pels and Verhoef, 2004) and the competition between congested airports (see Basso and Zhang, 2007c) are not examined in the present analysis. In addition, the network benefits associated with the hub and spoke system, which may lead to flight delays (see Mayer and Sinai, 2003), are not considered in our paper.
congestion in the period is assumed. Thus, the off-peak traffic in equilibrium is assumed to be small enough relative to airport capacity. However, the benefits from peak travel depend on both $\theta$ and $n_p$, which denotes the number of flights in the peak period. So the peak-travel benefits are given by:

$$B_p(\theta, n_p) = b_p(\theta) - H(\theta)t(n_p),$$

where $b_p(\theta)$ represents the gross benefit of peak travel. Here we assume $b'_p, b'_o > 0$, i.e., the (gross) travel benefits are higher for a high-$\theta$ passenger than a low-$\theta$ passenger. As such, $\theta$ may be interpreted as an index of the passenger’s tendency to travel on business (as opposed to leisure travel), as travel is a crucial job requirement for business travelers. $t(n_p)$ is the additional travel time (for example, in hours) due to congestion, which is increasing in $n_p$; $H(\theta)$ is the VTTS for passenger $\theta$. We assume that a passenger’s VTTS and gross travel benefit are correlated. In practice, passengers’ with higher gross travel benefits, such as business travelers, also have higher VTTS, as discussed in the introduction. Thus we further assume $H'(\cdot) > 0$. Note that if we consider constant time cost across passengers, $H(\cdot)$ is a constant and the model is reduced to that in Brueckner (2002).

To focus on the air travel market, we assume that consumers’ utility functions are quasilinear, so that the direct utility functions are:
\[ V(\theta) = \begin{cases} 
  x & \text{if not travel} \\
  x + b_p(\theta) & \text{if travel in the off-peak period} \\
  x + B_p(\theta) & \text{if travel in the peak period} 
\end{cases} \]

where \( x \) is consumption expenditure on other goods. Consumers maximize utility by choosing \( x \) and making a traveling decision (travel in the peak or off-peak period or not travel) that is subject to the budget constraint \( x + f_h \leq Y \), where \( f_h \) is the airfare in period \( h \in (o, p) \) the consumer chooses, or \( f_h = 0 \) for consumers choosing not to travel. \( Y \) denotes consumers’ income and is assumed to be uniform across consumers.

Moreover, since business travel must occur during the early and late peak hours to avoid disruption of the work day, peak-travel benefits should increase at a higher rate relative to off-peak benefits as \( \theta \) increases, yielding \( b'_p(\theta) - H'(\theta)\nu(n_p) > b'_o(\theta) \) for all \( \theta \). This is referred to as the single-crossing assumption. The assumption ensures that if a traveler with lower \( \theta \) travels in the peak period, then the counterpart with higher \( \theta \) must also travel in the peak period. It implies that, in the interior solution case, \( \Phi > \theta^* > \underline{\theta} > 0 \), where \( \theta^* \) and \( \underline{\theta} \) denote consumers who are indifferent to travel between peak and off-peak, and travel off-peak and not travel, respectively. Thus, consumers with \( \theta \in [\theta^*, \Phi] \) will travel in the peak period; consumers with \( \theta \in [\underline{\theta}, \theta^*) \) will travel in the off-peak period; and consumers with \( \theta \in (0, \underline{\theta}) \) will not travel. Furthermore, peak and off-peak

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17 In this paper, we consider the airport capacity is exogenously given. As a result, the congestion delays only depend on the number of peak flights. The case of variable and endogenous capacity is examined in
travel would be vertically differentiated, such that all passengers will prefer traveling in the peak period as opposed to the off-peak period with identical delays and air fares. In other words, \( b_p(\theta) > b_o(\theta) \) for all \( \theta \). This vertical-differentiation feature of air travel can arise if the peak period represents the day’s more desirable travel time.

Solving the consumer problem and by the definition of \( \theta \) and \( \theta^* \), we have:

\[
f_o = b_o(\theta), \quad (3)
\]

\[
f_p = B_p(\theta^*, n_p) - b_o(\theta^*) + f_o = b_p(\theta^*) - H(\theta^*)\tau(n_p) - b_o(\theta^*) + f_o. \quad (4)
\]

To obtain an interior solution, we assume that \( b_p(\theta) > b_o(\theta) \) holds for high \( \theta \), and \( B_p(\theta, n_p) < b_o(\theta) \) holds for low \( \theta \) in equilibrium, respectively. Note that the latter assumption is different from that in Brueckner (2002, 2005), in which passengers are not vertically differentiated (i.e., \( b_p(\theta) < b_o(\theta) \) for low- \( \theta \) passengers). More discussion about the condition for interior solutions in the vertically-differentiated case can be found in Basso and Zhang (2007b).

4. Carriers’ Competition

To solve the subgame perfect equilibrium, in this section we analyze the carriers’ Cournot competition among $N$ carriers in the second stage. We denote $n^k_p$ and $n^k_o$ are the number of flights chosen by airline $k$, in the peak and off-peak periods, respectively. Thus, $n_k = \sum_h n^k_h$ for $h \in (o, p)$. These airlines are assumed to be symmetric such that they have a zero fixed cost, a constant operating cost per flight, $c$, and an additional operating cost per flight due to peak-period congestion, $g(n_p)$, with $g'(\cdot) > 0$. As in Brueckner (2002, 2005), all flights are assumed to use identical aircraft with fixed seat capacity, $s$, and a 100% load factor is assumed.

Given the airport charges, $p_p$ and $p_o$, in the peak and off-peak periods, respectively, each airline, $k$, chooses quantities to maximize its own profit:

$$\max_{n^k_p, n^k_o} \pi^k(n^k_p, n^k_o; n^k_p, n^k_o) = f_p s n^k_p + f_p s n^k_o - (n^k_p + n^k_o)c - n^k_p g(n_p) - p_p n^k_o - p_p n^k_p \quad (5)$$

Aggregating all flights by all the carriers, we have $\Phi - \theta^* = s \sum n^k_p$ and $
\theta = \Phi - s \sum (n^k_p + n^k_o)$. By conditions (3) and (4), the peak and off-peak fares can be rewritten as:

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18 Cournot behavior has been assumed in Brueckner (2002, 2005), Pels and Verhoef (2004), Zhang and Zhang (2006), and Basso and Zhang (2007b). Brander and Zhang (1990), and Oum, Zhang and Zhang (1993), for example, find some empirical evidence that rivalry between airlines is consistent with Cournot behavior.

19 In an early study, Carlin and Park (1970) estimated the marginal delay costs for LaGuardia Airport by summing up the costs of aircraft owners and passengers.
\[ f_o = b_o[\Phi - s\sum(n^o_p + n^o_n)], \quad (6) \]
\[ f_p = B_p(\Phi - s\sum n^k_p) - b_o(\Phi - s\sum n^k_o) + b_o[\Phi - s\sum(n^k_p + n^k_n)]. \quad (7) \]

By substituting (6) and (7) into (5), and solving the maximization problem, the Cournot equilibrium is characterized by the first-order conditions (assuming the second-order conditions),

\[ \Omega_o = b_o(\theta) - b_o(\theta)(n^o_p + n^o_n)s - \frac{P_o}{s} - \frac{c}{s} = 0, \quad \forall k, \quad (8) \]
\[ \Omega_p = [b_p(\theta^*) - H(\theta^*)t(n_p) - b_o(\theta^*)] \\
- [n^k_pH(\theta^*)t(n_p) - (n^k_p/n_p)(\Phi - \theta^*)H'(\theta^*)t(n_p)] - \frac{1}{s}[g(n_p) + n^k_pg'(n_p)] \\
- (n^k_p/n_p)(\Phi - \theta^*)[b_p(\theta^*) - b_o(\theta^*)] - \frac{(p_p - p_o)}{s} = 0, \quad \forall k. \quad (9) \]

We further assume that a carrier’s marginal profit declines when another carrier’s output rises:

\[ \frac{\partial^2 \pi^k}{\partial n^k_o \partial n^j_o} < 0, \quad j \neq k \quad \text{and} \quad h \in (o, p). \quad (10) \]

Conditions (10) imply the carriers’ outputs are ‘strategic substitutes’ (Bulow, et al., 1985) and ensure that various comparative static properties are ‘well defined’ (see Dixit, 1986).

By conditions (8) and (9), imposing symmetry and adding up, we obtain:
\[ b_o(\theta) = \frac{c}{s} + \frac{p_o}{s} + \frac{(\Phi - \theta)}{N} b'_o(\theta), \]  

(11)

\[ [b_p(\theta^*) - H(\theta^*) \ell(n_p) - b_o(\theta^*)] \]

\[ = \frac{1}{s} g(n_p) + \frac{(p_p - p_o)}{s} + \frac{(\Phi - \theta^*)}{N} \left[ \frac{1}{s} H(\theta^*) \ell'(n_p) - H'(\theta^*) \ell(n_p) \right] \]

(12)

\[ + \frac{1}{N} \frac{n_p}{s} g'(n_p) + \frac{(\Phi - \theta^*)}{N} \left[ b_p'(\theta^*) - b_o'(\theta^*) \right]. \]

The intuition of these pricing rules has been discussed in the literature since Brueckner (2002). By (3), the LHS of (11) is the off-peak airfare. The first two terms on the RHS represent a carrier’s average cost per seat, which is the sum of operating cost and airport charge, in the off-peak period. The last term is a mark-up owing to market power in the Cournot oligopoly. As \(N\) increases, the market power mark-up diminishes.

By (3) and (4), the LHS of (12) is the premium in the peak fare over the off-peak fare. The first two terms on the RHS represent a carrier’s average cost per seat in the peak period over the off-peak, which is the sum of congestion costs incurred by the carrier and the difference between the peak and off-peak airport charges. The third term is the marginal change in delay cost incurred by marginal peak travelers with \(\theta = \theta^*\) due to a marginal increase in the number of peak travelers. On the other hand, it also implies a marginal decrease in the peak fare charged by the airlines (see equation (4)). As the decrease in the fare will affect the revenue from all peak travelers, the term is multiplied by \((\Phi - \theta^*)\), while it is also multiplied by \(1/N\), which suggests that each carrier only takes its own revenue change due to the decrease in the peak fare into account. Note that
different from the constant time cost case, the marginal delay cost imposed on travelers increases in $\theta$. Thus the marginal delay costs for other peak travelers with $\theta \in (\theta^*, \Phi]$ will be higher than that for the marginal traveler. The fourth term suggests that each carrier only charges for the congestion affecting its own operating cost in the peak period. For a monopoly carrier, $N = 1$, the marginal congestion cost on its flights (i.e., $g'()$) is fully internalized (charged). On the other extreme, for atomistic (perfectly competitive) carriers, $N \to \infty$, the congestion cost is totally ignored by each carrier. For $1 < N < \infty$, partial internalization is obtained. Again, the fifth term is a mark-up owing to market power in the Cournot oligopoly.

The comparative static results concerning the carriers’ aggregate output with respect to airport charges $p_p$ and $p_o$ are now derived. Totally differentiating (8) and (9) with respect to airport charges $p_p$ and $p_o$, and by the second-order conditions and (10), we obtain:

$$\frac{\partial n_p}{\partial p_p} < 0, \frac{\partial n_o}{\partial p_p} > 0, \quad (13)$$

$$\frac{\partial n_p}{\partial p_o} > 0, \frac{\partial n_o}{\partial p_o} < 0. \quad (14)$$
Inequalities (13) and (14) suggest that the number of flights in a period is decreasing in airport charges of the period, while it increases in that of the other period.\textsuperscript{20} The comparative static results will be used in the welfare analysis in Section 6.

5. Airport Pricing

In the airport pricing stage (stage 1) the airport chooses peak and off-peak charges, taking the subsequent carrier and consumer behavior into account to maximize the social welfare – the sum of airport and airlines profits, and passengers’ utility. To obtain the optimal charges, we first derive the optimal allocation of passenger, and then discuss what airport charges can induce such optimal allocation. Thus the airport solves the following maximization problem:\textsuperscript{21}

\[
Max \ SW = \int_{\theta^*}^{\theta} b_o(\theta) d\theta + \int_{\theta^*}^{\theta} \left[ b_p(\theta) - H(\theta)\tau(n_p) \right] d\theta - (n_o + n_p)c - n_p g(n_p). \tag{15}
\]

The first-order conditions yield:

\[
b_o(\theta) - c/s = 0, \tag{16}
\]

\[
[b_p(\theta^*) - H(\theta^*)\tau(n_p) - b_o(\theta^*), \frac{1}{s} \tau'(n_p) H(\theta) d\theta - \frac{1}{s} [g(n_p) + n_p g'(n_p)] = 0. \tag{17}
\]

\textsuperscript{20} Similar results are found in Basso and Zhang (2007b).

\textsuperscript{21} For simplicity, the airport’s operating costs are normalized to zero.
Equation (16) suggests that the travel benefit of passenger with $\theta$ in social optimum should be equal to the flight operating cost per seat. This result is equivalent to the one obtained by Brueckner (2002). Intuitively, in the optimal allocation between travelers and non-travelers we only need to consider the operating cost and off-peak travel benefits, which do not involve the peak benefit function upon which variable passenger time costs are considered.

The terms in the first bracket of (17) represent the difference of the marginal traveler’s ($\theta = \theta'$) travel benefits between the peak and off-peak periods. The second term in (17) captures the congestion effect due to the marginal traveler: to serve this passenger, the number of peak flights should be increased by $1/s$. This term thus represents the total additional time costs imposed on the peak passengers when shifting the marginal traveler to the peak period. The last term in (17) is the additional carriers’ operating cost of shifting the traveler from the off-peak period to the peak. Thus, equation (17) suggests that the marginal costs and benefits of switching the marginal traveler from the off-peak period to the peak are equal in the social optimum.

Next, we turn to the discussion of the optimal airport pricing. As noted above, the optimal airport pricing is set such that the optimal allocation of passengers can be achieved. Thus, conditions (16) and (17) are satisfied. By comparing conditions (11) and (12) and conditions (16) and (17), the optimal airport pricing can be obtained as follow:

$$p_o = -\frac{s(\Phi - \theta)}{N} b_o'(\theta),$$  \hspace{1cm} (18)
Equation (18) suggests that there is a subsidy for off-peak fares to correct the ‘market distortion’ due to carriers’ market power. Specifically, for atomistic carriers, there is no market distortion at the carrier level and so the subsidy is unnecessary in the social optimal airport charge. Note that although a subsidy to off-peak flights is welfare-improving, it may still be politically infeasible to have subsidies from the government to the industry. Furthermore, this may leave the airport in a position of financial deficit, if the optimal airport charge is negative.

Equation (19) suggests the premium paid by carriers using the airport in the peak period. The third term of (19) is included to induce the carriers to fully internalize congestion costs imposed on all flights – as discussed in Section 3, each carrier only charges for the congestion affecting its own flights. The last term in (19) is positive by the single crossing condition. Again, as in (18), this term is related to the ‘market distortion’ correction due to carriers’ market power.

The first and second terms of (19) are the difference between marginal congestion costs (incurred by peak travelers) and the congestion costs internalized at the carrier level. If the first term is larger than the second term, it implies that the carriers do not fully
internalize the congestion costs. By comparing the two terms, we have the following proposition:

**Proposition 1.** The congestion costs may not be fully internalized at the carrier level under different market structures (i.e., for all $N$), and thus the congestion pricing is always necessary.

**Proof:**

\[ t'(n_p) \int_\theta^\phi H(\theta) d\theta - \frac{(\Phi - \theta^*)}{N} \left[ H(\theta^*) t'(n_p) - s H'(\theta^*) u(n_p) \right] \]

\[ > t'(n_p) \int_\theta^\phi H(\theta) d\theta - (\Phi - \theta^*) H(\theta^*) + \frac{s(\Phi - \theta^*)}{N} H'(\theta^*) u(n_p) \]

\[ > \frac{s(\Phi - \theta^*)}{N} H'(\theta^*) u(n_p) \] (recall $H(\cdot)$ is an increasing function.)

\[ > 0 \quad Q.E.D. \]

Proposition 1 suggests that there is no market structure that induces full internalization of congestion at the carrier level. This result is different from the literature (e.g., Brueckner, 2005; Zhang and Zhang, 2006; Basso and Zhang 2007b), which suggests that a congestion toll is unnecessary for an airport served by a monopoly carrier, as in the case the congestion is fully internalized by the carrier. The intuition is as follows: To maximize its profit, the monopolist will only consider the marginal traveler’s ($\theta = \theta^*$)

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22 For instance, Section VI. B, Paragraph 12 of the Use of Airport Revenue Policy states: “DOT policy forbids direct subsidy of air carrier operations. Direct subsidies are considered to be payments of airport funds to carriers for air service.”
tradeoff in choosing the peak and off-peak periods. Different from a social welfare-maximizing airport, the monopoly carrier will have no incentive to take into account the costs and benefits of inframarginal travelers with \( \theta > \theta^* \), who have higher time valuations than the marginal counterparts in our variable time cost case. Thus the congestion cost is not fully internalized by the monopoly carrier. Note that the first three terms of (19) can be considered as a ‘pure’ congestion toll, which is positive, and are included so as to induce full internalization of congestion at the carrier level. On the other hand, for \( H'(\cdot) = 0 \), the monopoly will fully internalize the congestion as discussed in the literature. Furthermore, if the monopoly carrier can perfectly price discriminate passengers within a period, it will also fully internalize the congestion cost as a social welfare-maximizing airport does. It is because the monopoly carrier can charge each passenger for their time cost savings by different fares.\(^{23}\)

The result in Proposition 1 is also discussed in Brueckner (2002) about the effects of non-separability. In this regard, the proposition can be considered as providing a formal proof of Brueckner’s result with specific functional forms. Moreover, this can provide a better framework to examine the underlying factors affecting the extent of congestion internalization and peak allocation. As mentioned, the uninternalized congestion costs can be represented by the difference between the first two terms in (19). The fact that the extent of congestion internalization decreases in \( N \) has already been discussed in the literature. Thus we will now focus on other factors in the following

\(^{23}\) The result that a perfect price-discriminating monopoly carrier can induce the social optimum is also discussed in Brueckner (2002) under the assumption of homogenous passengers. In addition, Hofmann (2007) shows that in a model with heterogeneous insured population and the presence of (positive) externality, a monopolistic insurer can achieve the social optimum by engaging in premium discrimination.
discussion by considering the monopoly case (i.e., \(N=1\)). In such case, the uninternalized congestion costs (i.e., the difference between the first two terms) are:

\[
\int g \left( n_p \right) \left[ H(\theta) - H(\theta^*) \right] d\theta + s(\Phi - \theta^*) H'(\theta^*) r(n_p).
\] (20)

The first term of (20) is positive and increases in the difference between \(H(\theta^*)\) and \(H(\theta)\) for \(\theta \in (\theta^*, \Phi]\). Thus, if the difference between the time valuations of inframarginal passengers and marginal passengers increases, the uninternalized congestion cost increases. The second term of (20) is also positive and suggests that the larger the \(H'(\theta^*)\), the greater the amount of uninternalized congestion.

### 6. Welfare Analysis

As argued in Section 5, the imposition of congestion toll can induce the full internalization of congestion delays at the carrier level. Thus social welfare may be improved. Yet the welfare implications on different groups are uncertain. The major concern here is how the revenue from congestion pricing is re-distributed. In this section, we will consider the case that the revenue will be regarded as a source of airport revenue and will not be re-distributed to air carriers and travelers. It is because as noted in the introduction, an effective re-distributive mechanism is usually not in place. At the same time, as discussed above, a direct subsidy to air carriers and travelers is less observed in
practice. Thus we will focus on the pure congestion toll in the peak period (the first three terms in (19)) as in Brueckner (2002, 2005), thus the peak charge is equal to:

$$p_p = t'(n_p) \int \frac{\Phi - \Theta^*}{\Theta^* - \Theta} \left[ H(\Theta) \frac{\Theta - \Theta^*}{\Theta^*} \right] + \frac{N-1}{N} \frac{1}{\Theta^* - \Theta} \left[ H(\Theta^*) \frac{(\Theta^* - \Theta) \frac{\Theta^*}{\Theta^*}}{\Theta^* - \Theta} - sH(\Theta^*) t(n_p) \right],$$  \quad (21)

which is positive as discussed above. We will further discuss the welfare implications of the imposition of the optimal airport pricing given in (18) and (19) in our numerical simulation.

In the following, we will examine the welfare implications of the imposition of the congestion toll on airport, air carriers and travelers. First, the airport will be better-off as the airport profit is increased from zero to positive after the imposition of the congestion pricing.

Next we consider the change in consumer utility. After the imposition of the positive congestion toll, some passengers previously traveling in the peak period will choose to travel in the off-peak period (by inequalities (13) and $\Theta$ being unchanged after the imposition of the congestion toll in the peak period). For $\Theta^*$ and $\tilde{\Theta}^*$ denoting the marginal passenger between the peak and off-peak periods before and after the imposition of the congestion pricing, respectively, we have $\tilde{\Theta}^* > \Theta^*$. Thus we compare three groups of travelers, who may be affected by the imposition of the congestion toll. First, travelers travel in the peak period before and after the congestion toll is imposed
(i.e., \( \tilde{\theta}^* < \theta \leq \Phi \)). Second, travelers change from traveling in the peak period to the off-peak period (i.e., \( \theta' \leq \theta < \Phi \)). Third, travelers travel in the off-peak period before and after the congestion toll is imposed (i.e., \( \theta \leq \theta < \theta^* \)).

Equation (11) suggests that the off-peak fare will not change after the imposition of the congestion toll. On the other hand, the off-peak travel benefits will not change even though the number of off-peak flights increases. Recall the off-peak travel benefit is independent of \( n_o \). As a result, \( \theta_3 \)'s utility will not change with the imposition of the congestion toll.

Second, we consider the change in \( \theta_2 \)'s utility. Before the imposition of the congestion toll, \( \theta_2 \)'s utility is equal to:

\[
U_{2}^B = b_p(\theta) - H(\theta)u(n_p^B) - f_p^B > b_o(\theta) - f_o^B,
\]  

where the superscript ‘\( B \)’ represents variables before the imposition of the congestion toll; and \( n_p^B \) is the number of peak flights before the imposition of the congestion toll in equilibrium. The second inequality is because passengers with \( \theta_2 \) choose to travel in the peak period instead of the off-peak period. As \( \theta_2 \) will travel in the off-peak period after the imposition of the congestion toll, \( \theta_2 \)'s utility is equal to:
where superscript ‘A’ represents variables after the imposition of the congestion toll.

As the off-peak fare will not change after the imposition of the congestion toll, and by (21) and (22), we have:

\[ U^B_2 > U^A_2, \]

which suggests that \( \theta_2 \) will be worse-off after the imposition of the congestion toll.

Furthermore, by (21), (22) and the fact that passengers with \( \theta_2 \) prefer to travel in the off-peak period after the imposition of the congestion toll, we have:

\[ H(\theta_2)[\tau(n^B_p) - \tau(n^A_p)] + (f^B_p - f^A_p) < 0, \]  

(23)

where \( n^A_p \) is the number of peak flights after the imposition of the congestion toll in equilibrium.

As there are fewer passengers in the peak period after the imposition of the congestion pricing (i.e., \( n^B_p > n^A_p \)), we have \( \tau(n^B_p) > \tau(n^A_p) \). Hence, the first term on the RHS of (23) is positive and represents the time cost saving of passengers with \( \theta_2 \) after
the imposition of the congestion toll if they traveled in the peak period. On the other hand, as there are fewer people who will travel in the peak period, the peak fare should increase after the imposition of the congestion toll as \( \frac{\partial f_p}{\partial \theta^*} > 0 \) (by the assumption that \( b_p'(\theta) - H'(\theta)t(n_p) > b_o'(\theta) \) and (4)). Thus the second term on the RHS of (23) is negative. Inequality (23) suggests that after the imposition of the congestion pricing, the time cost saving for \( \theta_2 \) is not enough to compensate for the increase in peak airfare if they traveled in the peak period.

For passengers with \( \theta_1 \), they will travel in the peak period before and after the imposition of the congestion toll. The difference in \( \theta_1 \)'s utility before and after the imposition of the congestion toll is:

\[
U^A - U^B = H(\theta_1)(t(n^B_p) - t(n^A_p)) + (f^B_p - f^A_p).
\]  

(24)

Again, the first term on the RHS of (24) is positive and represents the time cost saving of passengers with \( \theta_1 \) after the imposition of the congestion toll. The second term on the RHS of (24) is negative as argued and represents the difference of the fares before and after the imposition of the congestion pricing. It shows that the change in \( \theta_1 \)'s utility can be positive or negative, which depends on his/her time valuation, as it determines the magnitude of benefits from the time cost saving after the imposition of the congestion toll. For travelers who have large \( H(\theta) \), their change in utility can be positive due to the substantial benefits from the time cost saving. However, in the Brueckner (2002) case,
where $H(\theta_1) = H(\theta_2)$, (23) and (24) imply $U_i^d - U_i^b < 0$, which suggests that $\theta_i$ will be worse-off after the imposition of the congestion toll. In other words, if we assume that the value of time for all passengers is the same (i.e., $H(\cdot)$ is constant), no passengers will be better-off if the positive congestion toll is imposed. In the numerical simulation in Section 7, we will further illustrate that passengers with a high value of time may be better-off after the imposition of the congestion pricing. The above discussion leads to the following proposition:

**Proposition 2** After the imposition of the congestion pricing, (i) the original off-peak travelers will have no change in utility; (ii) travelers shifting from the peak to the off-peak period will be worse-off; (iii) travelers in the peak period after the imposition of the congestion toll may be better-off or worse-off depending on their time valuation.

It is uncertain whether carriers are better-off or worse-off after the imposition of the congestion pricing. On one hand, the imposition of the congestion toll will increase the average cost per flight at a given congestion level. On the other hand, the imposition of the congestion toll not only decreases the number of peak passengers of a carrier, but also its rivals. This will lower the congestion cost experienced by the carrier. Thus, the imposition of the congestion toll may solve the coordination problem among air carriers facing the congestion externality. As a result, air carriers may be better-off or worse-off after the imposition of the congestion toll. The impact of the congestion toll on carriers will be further examined in the following section.
7. Numerical Simulation

This section conducts a simulation analysis to further illustrate the analytical results of our model. Here we consider symmetric airlines, and use specific functional forms and related parameters described as follows. First, we consider the case that the (gross) benefit functions, \( t(n_p) \) and \( H(\theta) \) are linear. Thus,

\[
b_o(\theta) = \alpha_o + \gamma_o \theta,
\]

\[
B_p(\theta, n_p) = b_p(\theta) - H(\theta)t(n_p) = \alpha_p + \gamma_p \theta - (v + \phi \theta)(t(n_p)),
\]

where \( \alpha_o, \gamma_o, \alpha_p, \gamma_p, t, v, \phi \geq 0 \), \( \alpha_p \geq \alpha_o \) and \( \gamma_p \geq \gamma_o \). Moreover, to illustrate the importance of the variable time cost in the airport congestion pricing analysis, we consider different slopes of \( H(\theta) \), namely \( \phi = 0, 0.0001, 0.0002, 0.0003 \) and \( 0.0004 \). For comparison among different \( \phi \)s, we assume \( v = 1 - \phi(\Phi/2) \), which suggests that for different \( \phi \)s, the time valuations (i.e., \( H(\theta) \)) of the median consumers with \( \theta = \Phi/2 \) are all equal to 1. The \( H(\theta) \) for different \( \phi \)s is shown in Figure 2.

Furthermore, we consider carriers facing constant marginal operating cost function and constant marginal delay cost. Thus, the total cost of carrier \( k \) is:
\[(n^k_o + n^k_p)c + n^k_p \varphi n_p\]

where \(c, \varphi \geq 0\).

Table 2 shows the parameterization for our simulation exercise. Further we assume that \(\Phi = 5,000\), which implies that the market size is 5,000. Note that it is not the purpose of this paper to describe a real-life aviation network accurately. Thus our choice of parameters does not correspond to any actual cases. Yet we calculated the equilibrium price elasticities of demand and compared them with estimates from the literature to confirm the plausibility of the parameterization. In particular, we found that the calculated price elasticities in equilibrium in the simulation results are between -0.52 and -1.29, which are consistent with the existing empirical literature.24 At last, we will also conduct a sensitivity analysis for some crucial parameters to check the robustness of our results.

[Table 2 here]

Table 3 presents the simulation results for passenger allocation under different market structures and \(\varphi\)s. The results are consistent with our analytical results. First, \(\theta\) (the allocation between travelers and non-travelers), as expected, remains the same for each market structure among cases with different \(\varphi\)s. As off-peak passengers do not experience any congestion in our model, the allocation will only depend on the operating

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24 The price elasticity of the air passenger market estimated by Brons, et al. (2002) is -1.146.
costs, off-peak travel benefits and market power. Second, the socially optimal $\theta^*$ (the allocation between peak and off-peak travelers) increases in $\phi$, which suggests that there are fewer people who will travel in the peak period when the value of time is more sensitive to the change in $\theta$ (i.e., larger $H'(\cdot)$). This is because the total additional time cost to peak passengers when shifting the marginal traveler to the peak period is larger when $H'(\cdot)$ is large, as discussed in Section 5. Third, the $\theta^*$'s are larger under monopoly and smaller under an oligopoly (and perfect competition) than the social optimum, which indicates underuse of the peak period under monopoly, while it is overused under an oligopoly (and perfect competition).

[Table 3 here]

Figure 3 plots the congestion toll (i.e., the uninternalized congestion costs) against the market structure variable $N$, the number of airlines at the airport. This is consistent with our analytical results. First, under monopoly while no congestion toll is required for $\phi = 0$ (as discussed in Brueckner, 2002), a positive congestion toll should be imposed in the variable passenger time cost cases. This result is consistent with our Proposition 1, which suggests that, under monopoly, the carrier does not fully internalize the congestion cost as a social welfare-maximizing airport does. Thus, a positive congestion toll should be imposed in the variable passenger time cost cases. The figure also supports the argument made by Brueckner (and this paper) that congestion is negatively correlated with airport concentration. Furthermore, the marginal increase in the optimal congestion toll falls as $N$ rises. That is, although airport congestion is worsened owing to more
serious externalities as the number of carriers rises, the marginal external effect falls. In particular, Figure 3 shows that the level of congestion toll remains almost unchanged for $N > 5$ suggesting, therefore, that for the practical purpose of congestion pricing we might just treat $N > 5$ as atomistic airlines and apply the results of the road-pricing literature – charging the toll as in perfect competition (see for example, Small, 1992 and Small and Verhoef, 2007). Moreover, as $H'(\cdot)$ is larger, the congestion toll is larger under different market structures. Intuitively, the uninternalized congestion costs are larger, if $H'(\cdot)$ is larger. Thus, a larger congestion toll is required to achieve the social optimum.

[Figure 3 here]

Table 4 shows the welfare change after the imposition of the congestion pricing. It suggests that the congestion toll is not necessarily welfare-improving. It is because the congestion toll decreases the number of peak travelers, which will further reinforce the distortion due to downstream carrier market-power markups. However, it is noted that they are all welfare-improving in different cases under perfect competition. It is because no marker-power distortion exists in such cases. As a result, the social welfare optimum can be achieved by imposing the congestion toll under perfect competition.

[Table 4 here]
In Section 6, we discuss the welfare change across different groups after the imposition of the congestion pricing. Table 5 presents the change in consumer surplus, producer surplus and airport revenue after the imposition of the congestion toll in the duopoly case. It shows that the consumer and producer surplus will decrease, which implies that both carriers and consumers will be worse-off after the imposition of the congestion toll. In particular, the consumer and producer surplus in the peak period will decrease, while those in the off-peak period increase. Finally, the airport will be better-off as it receives positive revenue from the congestion pricing. Nevertheless as both air carriers and most consumers are worse-off after the imposition of the congestion toll in our simulation results, the implementation of the pricing may then face strong opposition from them. This may explain why the congestion toll is still unpopular in reality, although it has strong support from economists based on efficiency arguments. On the other hand, Table 5 also shows that with a larger $H'(\cdot)$, the larger the social gain from imposing the congestion toll. This is because the uninternalized congestion increases in $\phi$. The result implies that if we ignore the heterogeneity in passenger time cost, we may underestimate the welfare gains from the implementation of the congestion pricing. Similar results are also found for different market structures.

[Table 5 here]

Note that any carriers’ welfare loss due to the congestion pricing may be easier to be offset by a re-distributive program between the airport and air carriers, or through vertical integration, while those solutions are more difficult to compensating the loss in
the consumer market. Thus the welfare impact on consumers is particularly important in
our welfare-redistributive analysis. Hence we also take a closer look at the consumer side
by investigating the change in utility across different consumer groups after the
imposition of the congestion toll. Table 6 presents the result with \( \phi = 0.0004 \). The result
is consistent with Proposition 2. First, the travelers shifting from the peak to the off-peak
period are worse-off. Second, the original off-peak travelers have no change in utility.
Third, the travelers staying in the peak period may be better-off or worse-off depending
on their time valuations. In particular, those having very high time valuations may be
better-off as they have significant gains from the time cost saving after the imposition of
the congestion toll. Nonetheless, in our simulation results, most travelers will not be
better-off after the imposition of the congestion toll. Furthermore, for \( \phi = 0, 0.0001 \) and
0.0002, all passengers will not be better-off after the imposition of the congestion toll.

[Table 6 here]

In order to achieve the social optimum, as also suggested by Pels and Verhoef
(2004), both congestion and market-power distortion should be taken into account to
determine optimal airport pricing. Thus, we also examine the welfare change after the
imposition of the optimal airport pricing given in equations (18) and (19). Table 7 shows
the calculated optimal airport pricing in our simulation exercise. Under monopoly, a
negative optimal charge should be imposed (i.e., subsidy). This suggests that the airport
is underused due to downstream carriers’ market power. Under oligopoly competition, a
positive optimal charge should be imposed, which suggests that the airport is underused
due to the congestion externalities in carrier competition. Moreover, the optimal airport pricing is less than the congestion toll. This is because market-power mark-up alleviates the congestion at the airport. Finally, the congestion toll is equivalent to the optimal airport charge under perfect competition as market power vanishes. Table 8 shows the change in welfare if the optimal airport pricing is imposed. Under monopoly, the welfare is improved by almost 30%. The gains decrease initially as $N$ rises and falls as $N$ approaches infinity.

[Table 7 here]

[Table 8 here]

To check the robustness of the simulation results, we also conducted sensitivity analysis by varying the parameters in the time cost and travel benefit functions, while all of the remaining parameters are kept as above. In particular, we conduct the sensitivity analysis, in which (i) $t$ is increased from 100 to 200; (ii) $\gamma_p$ is increased from 1.2 to 1.5. We found that these changes yielded similar results as those in the benchmark case.

8. Concluding Remarks

This paper has examined the airport congestion pricing problem that arises when passengers are heterogeneous in values of time, and has investigated welfare-redistributive issues after the imposition of the congestion pricing scheme. In practice, the
value of time is different among passengers, depending on their characteristics such as incomes and travel purposes. Although this fact is supported by extensive empirical work, it is less discussed in the analytical work in the literature. The present analysis is a first attempt to study the implications of variable passenger time costs in the airport congestion pricing analysis.

In the variable passenger time cost case, we found that, under different market structures at the downstream carrier level, from monopoly to perfect competition, congestion delays may not be fully internalized by the carriers due to two reasons. First, in its profit maximization, each carrier only considers the delays affecting its marginal passengers, who are indifferent to travel in the peak and off-peak periods, as the equilibrium peak fare only depends on their net travel benefits (the sum of gross travel benefits minus delay costs). Thus the delay costs on other passengers in the peak period, who have higher values of time than marginal passengers, will be ignored. This will lead to the result that congestion delays are not fully internalized by the carriers. Second, as several authors recently pointed out, each oligopoly airline at an airport only internalizes the congestion one of its flights imposing on its other flights but not that on its rivals. These two reasons further suggest that a social welfare-maximizing airport is always required to impose a positive congestion toll under different market structures, which leads the carriers to fully internalize congestion delays.

Furthermore, we also conducted a welfare analysis with an implementation of the congestion pricing scheme. Without a re-distributive mechanism, passengers will never
be better-off if the congestion pricing scheme is implemented in the constant time cost case, while passengers with high values of time could be better-off in the variable passenger time cost case. On the other hand, the airport will always be better-off by imposing the congestion pricing scheme. These results are further illustrated in our simulation analysis. In addition, airlines are found to be worse-off in our simulation exercise if the congestion pricing scheme is implemented. Thus, our results suggest that although the implementation of the congestion pricing may be welfare-improving, it may not be Pareto-improving. Being considered as a politically sensitive industry, any airport policy, including a change in its pricing, is difficult to be implemented without support from its users, namely airlines and passengers. This may explain why the congestion pricing appears unpopular in practice.

A valuable extension to this paper is to consider an asymmetric airline case. This paper found that passengers with high values of time may be better-off when congestion pricing is implemented. In practice, there is market segmentation in the airline market: legacy carriers usually serve a higher portion of business travelers, while low-cost carriers serve a higher portion of leisure travelers (see O’Connell and Williams, 2005). As a result, the implementation of congestion pricing will have different implications on legacy and low-cost carriers and their respective customers. In particular, the introduction of congestion pricing may induce an increase in demand for legacy carrier services due to the time cost savings in traveling. Considering the cost side, legacy carriers operate more flights during the congested period, for example, for hubbing, and thus operating cost savings due to a reduction in congestion in the period will be more significant for them.
Using data from the Minneapolis-St. Paul Airport, Daniel (2001) found that Northwest enjoys the greatest gain due to the implementation of congestion pricing as compared to regional counterparts. Thus, the decision of an airport to implement congestion pricing should also take the potential competitive issues in the downstream carrier market into account.
REFERENCES


**Figure 1a. Daily flight pattern at Hong Kong International Airport in 2007**

Note: Flight schedule on 8th November (Thursday) 2007; the runway capacity is 54 flights/hour. Source: HKIA website

**Figure 1b. Daily flight pattern at Hong Kong International Airport in 2020**

Note: Assuming (i) the average annual passenger growth is 5 percent (HKIA, “Master Plan 2020”); (ii) the flight increase in each period is proportional to the passenger growth; and (iii) the current capacity is kept unchanged.
Figure 2. Time valuation for different $\phi$s

Figure 3. The congestion toll under different market structures
Table 1. Flight delays in China (September 2007)

<table>
<thead>
<tr>
<th>Airline</th>
<th>Number of Flights</th>
<th>On-time</th>
<th>Delay</th>
<th>Percentage of Delays (%)</th>
<th>Year-to-Year change (%)</th>
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<tbody>
<tr>
<td>China Southern Airlines</td>
<td>32,956</td>
<td>6,094</td>
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<td>15.61</td>
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<td>Shandong Airlines</td>
<td>4,930</td>
<td>924</td>
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<td>15.78</td>
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<td>Hainan Airlines</td>
<td>8,356</td>
<td>1,643</td>
<td></td>
<td>16.43</td>
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<td>China Eastern Airlines</td>
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<td>16.45</td>
<td>9.63</td>
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<tr>
<td>Shanghai Airlines</td>
<td>5,200</td>
<td>1,092</td>
<td></td>
<td>17.36</td>
<td>1.80</td>
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<tr>
<td>Air China</td>
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<td></td>
<td>18.21</td>
<td>7.50</td>
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<tr>
<td>Xiamen Airlines</td>
<td>6,532</td>
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<td>Sichuan Airlines</td>
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<td>18.27</td>
<td>-1.49</td>
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<tr>
<td>Shenzhen Airlines</td>
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<td>5.68</td>
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<tr>
<td>Total</td>
<td>114,089</td>
<td>24,126</td>
<td></td>
<td>17.46</td>
<td>1.89</td>
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</table>

Source: CAAC website
Table 2. Parameter values for the numerical simulation

<table>
<thead>
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<th>Benefit functions</th>
<th>Airline cost function</th>
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<tr>
<td>$\alpha_o$</td>
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<td>$\alpha_p$</td>
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<tr>
<td>$\gamma_p$</td>
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<td>$t$</td>
<td>100</td>
</tr>
<tr>
<td>$c$</td>
<td>100,000</td>
</tr>
<tr>
<td>$s$</td>
<td>200</td>
</tr>
<tr>
<td>$\varphi$</td>
<td>4,000</td>
</tr>
</tbody>
</table>

Table 3. The allocation of passengers

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>Social Optimal</th>
<th>$N = 1$</th>
<th>$N = 2$</th>
<th>$N = 3$</th>
<th>$N \to \infty$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta$</td>
<td>$\theta^*$</td>
<td>$\theta$</td>
<td>$\theta^*$</td>
<td>$\theta$</td>
</tr>
<tr>
<td>0.0000</td>
<td>625</td>
<td>2,813</td>
<td>3,572</td>
<td>3,889</td>
<td>3,519</td>
</tr>
<tr>
<td>0.0001</td>
<td>625</td>
<td>2,813</td>
<td>3,713</td>
<td>3,943</td>
<td>3,666</td>
</tr>
<tr>
<td>0.0002</td>
<td>625</td>
<td>2,813</td>
<td>3,842</td>
<td>4,000</td>
<td>3,620</td>
</tr>
<tr>
<td>0.0003</td>
<td>625</td>
<td>2,813</td>
<td>3,956</td>
<td>4,060</td>
<td>3,682</td>
</tr>
<tr>
<td>0.0004</td>
<td>625</td>
<td>2,813</td>
<td>4,055</td>
<td>4,120</td>
<td>3,750</td>
</tr>
</tbody>
</table>

Table 4. Welfare with congestion toll (in millions)

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>Welfare</th>
<th>$%$ change</th>
<th>Welfare</th>
<th>$%$ change</th>
<th>Welfare</th>
<th>$%$ change</th>
<th>Welfare</th>
<th>$%$ change</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>7,099</td>
<td>0.00%</td>
<td>8.203</td>
<td>-0.36%</td>
<td>8.588</td>
<td>0.26%</td>
<td>9.084</td>
<td>5.11%</td>
</tr>
<tr>
<td>0.0001</td>
<td>6,935</td>
<td>-0.40%</td>
<td>8.038</td>
<td>-0.16%</td>
<td>8.422</td>
<td>0.79%</td>
<td>8.917</td>
<td>6.79%</td>
</tr>
<tr>
<td>0.0002</td>
<td>6.801</td>
<td>-0.58%</td>
<td>7.900</td>
<td>0.16%</td>
<td>8.283</td>
<td>1.42%</td>
<td>8.776</td>
<td>8.59%</td>
</tr>
<tr>
<td>0.0003</td>
<td>6.692</td>
<td>-0.62%</td>
<td>7.787</td>
<td>0.53%</td>
<td>8.168</td>
<td>2.07%</td>
<td>8.658</td>
<td>10.33%</td>
</tr>
<tr>
<td>0.0004</td>
<td>6.602</td>
<td>-0.72%</td>
<td>7.692</td>
<td>0.86%</td>
<td>8.071</td>
<td>2.62%</td>
<td>8.559</td>
<td>11.78%</td>
</tr>
</tbody>
</table>

Table 5. Welfare change with congestion toll ($N = 2$)

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>Off-peak Consumer Surplus</th>
<th>Peak Consumer Surplus</th>
<th>Off-peak Producer Surplus</th>
<th>Peak Producer Surplus</th>
<th>Airpot revenue</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0000</td>
<td>331,387</td>
<td>-472,750</td>
<td>307,824</td>
<td>-630,038</td>
<td>434,469</td>
<td>-29,108</td>
</tr>
<tr>
<td>0.0001</td>
<td>457,051</td>
<td>-589,590</td>
<td>402,270</td>
<td>-765,922</td>
<td>483,075</td>
<td>-13,116</td>
</tr>
<tr>
<td>0.0002</td>
<td>555,998</td>
<td>-659,640</td>
<td>466,400</td>
<td>-841,338</td>
<td>491,274</td>
<td>12,694</td>
</tr>
<tr>
<td>0.0003</td>
<td>624,190</td>
<td>-693,470</td>
<td>501,380</td>
<td>-869,516</td>
<td>478,184</td>
<td>40,767</td>
</tr>
<tr>
<td>0.0004</td>
<td>664,400</td>
<td>-379,520</td>
<td>513,040</td>
<td>-1,187,245</td>
<td>455,062</td>
<td>65,737</td>
</tr>
</tbody>
</table>
Table 6. Passengers’ utility change ($\phi = 0.0004$)

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>0</th>
<th>500</th>
<th>1000</th>
<th>1500</th>
<th>2000</th>
<th>2500</th>
<th>3500</th>
<th>4000</th>
<th>4500</th>
<th>5000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N = 1$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-26</td>
<td>-12</td>
<td></td>
</tr>
<tr>
<td>$N = 2$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-50</td>
<td>-175</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>$N = 3$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-50</td>
<td>-26</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>$N \rightarrow \infty$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>93</td>
<td>199</td>
<td></td>
</tr>
</tbody>
</table>

Table 7. Optimal airport pricings (in thousands)

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$N = 1$</th>
<th>$N = 2$</th>
<th>$N = 3$</th>
<th>$N \rightarrow \infty$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off-peak</td>
<td>Peak</td>
<td>Off-peak</td>
<td>Peak</td>
</tr>
<tr>
<td>0.0000</td>
<td>-700</td>
<td>-114</td>
<td>-350</td>
<td>14</td>
</tr>
<tr>
<td>0.0001</td>
<td>-700</td>
<td>-78</td>
<td>-350</td>
<td>37</td>
</tr>
<tr>
<td>0.0002</td>
<td>-700</td>
<td>-52</td>
<td>-350</td>
<td>53</td>
</tr>
<tr>
<td>0.0003</td>
<td>-700</td>
<td>-34</td>
<td>-350</td>
<td>65</td>
</tr>
<tr>
<td>0.0004</td>
<td>-700</td>
<td>-22</td>
<td>-350</td>
<td>74</td>
</tr>
</tbody>
</table>

Table 8. Welfare change with optimal airport pricing

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$N = 1$</th>
<th>$N = 2$</th>
<th>$N = 3$</th>
<th>$N \rightarrow \infty$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>27.97%</td>
<td>10.35%</td>
<td>6.05%</td>
<td>5.11%</td>
</tr>
<tr>
<td>0.0000</td>
<td>28.06%</td>
<td>10.76%</td>
<td>6.71%</td>
<td>6.79%</td>
</tr>
<tr>
<td>0.0001</td>
<td>28.28%</td>
<td>11.26%</td>
<td>7.45%</td>
<td>8.59%</td>
</tr>
<tr>
<td>0.0002</td>
<td>28.58%</td>
<td>11.77%</td>
<td>8.20%</td>
<td>10.33%</td>
</tr>
<tr>
<td>0.0003</td>
<td>28.90%</td>
<td>12.23%</td>
<td>8.82%</td>
<td>11.78%</td>
</tr>
</tbody>
</table>