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Congestion pricing and environmental cost at Guangzhou Baiyun International Airport

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ABSTRACT

To solve the problems related to resource constraints during peak periods—especially flight delays—congestion pricing, which is an important demand management tool, is proposed to ease airport congestion. A steady-state congestion model that includes the costs of airlines, passengers and the environment is established to calculate congestion fees for different times of day and different queue lengths. For the atomistic airline market, airline congestion fees are approximately 5000RMB to 10,000RMB during off-peak time. However, during peak time, congestion fees exceed 10,000RMB and can even reach 35,000RMB. These results show that airport congestion pricing can motivate airlines to move certain flights from the peak period and can slightly alter the scheduled departure times of other flights to avoid the rush of departures that occur on the hour at busy airports, thereby reducing the cost of delays caused by congestion. Moreover, congestion pricing that includes environmental cost has been shown to contribute to energy conservation and emissions reduction.

1. Introduction

Air transportation has realized impressive growth during the last several decades and is expected to grow at high rates in the future. As the civil aviation industry continues its dramatic development, the phenomena of flight delays and airport congestion are becoming increasingly problematic. One means to reduce congestion is the physical expansion of infrastructure at airports. However, airport expansion stimulates new increases in demand and thus alleviates congestion only temporarily, as stated in Downs' Law. Moreover, the degree to which airport capacity can be expanded is greatly limited. For many airports, the physical expansion of infrastructure is difficult or even impossible due to political and environmental constraints (such as laws regarding excessive noise and air pollution, land use planning policies, and operational patterns and conventions).

To manage airport congestion, researchers going as far back as Levine (1969) and Carlin and Park (1970) have called for the application of a price mechanism similar to road congestion pricing. It is proposed that airports replace existing landing fees, which are based on an aircraft's weight, with efficient landing and takeoff tolls that are based on an aircraft's contribution to congestion (i.e., airport congestion pricing). Under such a pricing system, the landing fees paid by airlines would vary with the level of congestion at the airport and operating costs at peak hours would substantially increase compared to costs at off-peak hours, leading to a redistribution of traffic as airlines shift certain flights away from peak hours.

The literature on airport congestion pricing is relatively extensive. Earlier models drew upon road congestion models. As such, flights were treated as atomistic, like individual drivers. Daniel (1995) presented a sophisticated analysis of large hub airports using a stochastic bottleneck model to show the effects of congestion pricing at the Minneapolis-St. Paul Airport. Daniel (2001) extended this model by adding dynamically adjusting traffic rates, queuing delays, and congestion fees. As research continues, certain scholars have remarked that the 'atomistic' assumption may not hold for flights, because a congested airport is usually dominated by a few carriers with market power. Brueckner (2002) analyzed airport congestion when carriers are nonatomistic and showed that when an airport is dominated by a monopolist, congestion is fully internalized, which suggests that there is no role for congestion pricing under monopoly conditions. Pels and Verhoef (2004) developed a model where airlines had market power and discussed cooperation between different regulators to optimize the problem. Considering that congestion tolls can provide funds for the expansion of airport capacity, Zhang and Zhang (2006) investigated the implications of airline market structure for airport pricing, capacity, and congestion. Czerny (2010) adopted linear and non-linear models to analyze the relative welfare effects of slots and congestion pricing under uncertainty for a single airport and airport network. Basso and Zhang (2010) analyzed the different impacts of pricing and slot-allocation mechanisms on airports when profits were important due to budget constraints or profit

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maximization. Czerny and Zhang (2011) explored congestion pricing with two types of travelers (business and leisure passengers) that have different relative values of time and demonstrated that the existence of different traveler types could have a substantial impact on decisions regarding airport charges. Czerny and Zhang (2014) investigated congestion pricing by allowing carriers to price discriminate between different types of passengers when operating costs are constant and found that the discriminatory business fare always exceeds the uniform fare whereas the discriminatory leisure fare is lower than the uniform fare.

These previous models are theoretically complicated, and many of them remain within the academic domain; only a small number have been applied in empirical analysis. Daniel (2011) used the stochastic bottleneck model developed by Daniel (1995, 2001) and Daniel and Harback (2008, 2009) to study four Canadian airports (in Toronto, Vancouver, Calgary, and Montreal) and calculated equilibrium congestion pricing schedules, traffic rates, queuing delays, layover times, and connection times by time of day. Moreover, when calculating external costs, previous papers have focused more on operating costs and ignored environmental costs, which seems inappropriate, especially given that environmental concerns are increasingly limiting the growth of the air transportation industry. The two most common forms of pollution generated by commercial flights are noise and aircraft engine emissions. Noise has the largest impact on the community that surrounds the airport, whereas engine emissions have both local and global impacts. Certain countries have started to implement market tools to control air pollution. In 1999, only 14 countries or regions in the world had some form of noise charges; by 2007, 23 countries and regions had noise-related charges (Lin, 2011a). In 1999, engine emissions charges were in place only at certain Swiss and Swedish airports, and these charges targeted local emissions only (Lu and Morrell, 2006). By 2007, pollution-related charges had been implemented at more airports, including Heathrow International Airport (Lin, 2011b). In this paper, environmental costs are added to the external costs and a steady-state congestion model is developed to investigate departure delays, structure, and the magnitude of optimal pricing at Guangzhou Baiyun International Airport.

2. The model of airport congestion

Airport congestion occurs when the demand for access to airport facilities exceeds the supply. In airports, supply may refer to runway capacity, because only one aircraft can occupy a runway at a given time. However, for queued departure flights, congestion is manifested on the taxiways leading to the runways. The model is shown in Fig. 1. The horizontal axis is the length of the departure queue of aircrafts wishing to take off at time *t*, which is defined as the number of aircrafts on the airfield that have pushed back from the gate but have yet to take off. The vertical axis refers to the costs of the taxi-out time, which is defined as the time between push-back and take off. The cost is a function of the taxi-out time and include the airlines' operating costs and passengers' time costs; environmental costs may or may not be included.

The marginal private cost (*MPC*) curve refers to the "private" costs incurred by a specific aircraft and its passengers for different lengths of the departure queue. It must be stated that a departure queue does not definitely imply congestion. As a service system, there must be an acceptable queue length at an airport, which is defined as the threshold of the congestion queue. Only when the queue at the airport is longer than the threshold of congestion queue, it is proper to estimate congestion pricing.

The marginal social cost (*MSC*) curve refers to the "social" costs incurred by a specific aircraft and its passengers. The gap between the two curves represents the externalities caused by congestion. It should be noted that *MSC* is always greater than *MPC* when environmental cost is calculated.

Time t_1 represents a situation where a queue has developed.

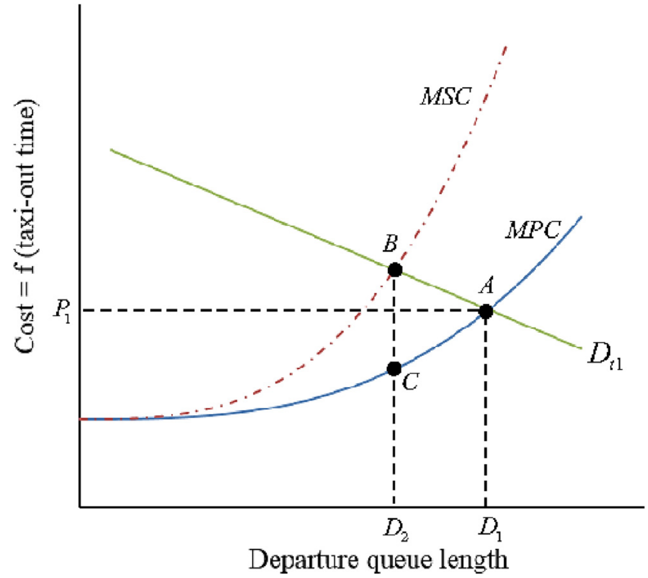

Fig. 1. The steady-state congestion model.

Without congestion pricing, airlines equate their demand with their private costs, which is the intersection of the demand function t_1 and *MPC* (shown as point *A*), and is where D_1 aircraft wish to depart. However, the optimal queue length is D_2, where the demand function t_1 intersects *MSC*. At this point, the marginal cost exceeds the private cost by distance *BC*, which represents the costs imposed on aircraft already in the queue at the time the marginal aircraft takes off. Assuming that price changes are not so severe that they significantly reduce the effective real income of airline passengers and shift the demand function, a congestion price of *BC* will produce an optimal number of flights.

Unlike urban road users, which are treated as atomistic, airport users, airlines—usually have market power. The base airlines in particular are likely to have market power, because a congested airport is usually dominated by a few carriers, each of which conducts a large number of flights at the airport. An additional flight at congestion time from airlines with high market shares will increase the externalities of other airlines and bring a negative effect upon itself. Moreover, Brueckner (2002) noted that the actual effects of airport congestion tolls depend on the market structure. A monopoly airline will fully internalize the congestion, meaning that there is no role for congestion pricing in this scenario. Under the Cournot oligopoly, carriers will internalize the congestion that they impose on themselves. Thus, a congestion price should only reflect delays imposed on other airlines and their respective passengers. Therefore, the congestion fee charged to an airline can be calculated as (1-proportion of an airline's market share of departures) multiplied by the distance *BC*.

3. Data and assumptions

This model for airport congestion pricing was applied to the Guangzhou Baiyun International Airport (CAN), which is one of the three major international hub airports in China. It is one of the busiest airports in Asia and in the world. Until September 2016, the route network of CAN included 216 global destinations in 43 countries and regions. Seventy airlines operate at CAN, including 45 foreign airlines and regional companies. In 2016, CAN was ranked 16th worldwide with a total passenger throughput of 59.78 million. After analyzing and calculating delay time and delay costs at CAN on 7th March 2013, the congestion tolls for various airlines at various times were calculated. There was a total of 529 departure flights on 7th March, including 90 international flights.

Costs during taxi-out time involve many elements, including the