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Airport congestion pricing and terminal investment: Effects of terminal congestion, passenger types, and concessions

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A B S T R A C T

None of the airport-pricing studies have differentiated the congestion incurred in the terminals from the congestion incurred on the runways. This paper models and connects the two kinds of congestion in one joint model. This is done by adopting a deterministic bottleneck model for the terminal to describe passengers' behavior, and a simpler static congestion model for the runway. We find that different from the results obtained in the literature, uniform airfare *does not* yield the first-best outcome when terminal congestion is explicitly taken into account. In particular, business passengers are at first-best charged a higher fare than leisure passengers if and only if their relative schedule-delay cost is higher. We further identify circumstances under which passengers are, given a uniform airport charge scheme, under- or over-charged with respect to the terminal charge. Furthermore, when concession surplus is added to the analysis, the airport may raise (rather than reduce) the airport charge in order to induce more business passengers who in turn will lengthen leisure passengers' dwell time and hence increase their chance of purchasing concession goods. Finally, the impacts of terminal capacity expansion and time-varying terminal fine toll are discussed.

1. Introduction

Airport congestion has become an important and growing phenomenon in the airline industry. As a potential solution, imposition of congestion tolls has been proposed and widely discussed in the literature. Various factors that influence the design of airport congestion tolls have been examined. For example, airline market structure needs to be taken into account since airlines with market power may internalize the congestion cost they impose to their own flights (e.g., Daniel, 1995; Brueckner, 2002; Pels and Verhoef, 2004; Zhang and Zhang, 2006; Basso, 2008; Brueckner and Van Dender, 2008; Rupp, 2009; Flores-Fillol, 2010; Ater, 2012; Lin, 2013). Airport concessions should also be part of the picture, given that the number of passengers plays a different role in contributing to the airport's congestion level and concession revenues (e.g., Oum, et al. 2004; Czerny, 2006; Yang and Zhang, 2011; Bracaglia et al., 2014). The types of passengers may matter as well, because passengers of different types may have distinct responses to congestion tolls due to their different values of time (Czerny and Zhang, 2011, 2014b). D'Alfonso et al. (2013)

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investigated the interaction among these factors while incorporating the connection between congestion delays and concession consumption. They derived corresponding optimal airport charges based on the assumption that an increase in congestion delays will increase passengers' dwell time, and hence induce higher probability of their purchasing concession goods. This assumption does not reflect the fact that airport congestion may occur either in the terminals or on the runways.[1]

Interestingly, none of the previous studies have differentiated the congestion incurred in the terminals from the congestion incurred on the runways, despite of the fact that these two kinds of congestion clearly have different implications to airlines and airports in the above-mentioned contexts. In particular, terminal congestion seems to be less of a concern to the airlines' operations, but it will likely affect passenger behavior and airport concession activity to a large extent. On the other hand, runway congestion is more of an issue to the airlines but has less to do with airport concessions. In other words, airport concessions and passenger types are related more closely with terminal congestion than with runway congestion. For instance, passengers cannot control the time to take-off, but can choose when to arrive at the airport. Passengers can consume concessions during their dwell time at the terminal, but they are required to stay in aircraft and wait for their turns to take-off when the runway is congested and as a consequence, they are unable to purchase any concession goods during the wait. Therefore, separating these two kinds of airport congestion may help clarify and deepen our understanding of the interactions between different factors in designing an optimal airport charge. Furthermore, these two kinds of airport congestion show different characteristics, with terminal congestion being totally "atomistic" while runway congestion shows a certain degree of "internalization."[2]

Taken together, these observations suggest that it is important to investigate the impacts of separating terminal congestion from runway congestion, in order to improve our understanding of airport congestion and the design of an optimal airport toll. In this paper we treat terminal congestion and runway congestion as two different kinds of congestion, and consider both congestion types simultaneously in a single airport pricing model. To capture the difference between terminal and runway congestions, we adopt a deterministic bottleneck model for the terminal and a simpler static congestion model for the runways (the latter is standard in the recent airport pricing literature). The bottleneck model was introduced by Vickrey (1969) to account for congestion dynamics, in particular individual drivers' decision on when to depart their home during the morning rush hours. Arnott et al. (1990) derived the optimal coarse toll and optimal road capacity based on a bottleneck model with a fixed number of identical travelers, i.e. inelastic travel demand. Arnott et al. (1993) modified the previous studies by incorporating elastic travel demand. The model was then extended to cases where travelers are heterogeneous (e.g., Arnott et al., 1994; van den Berg and Verhoef, 2011). Compared with the conventional static congestion model which assumes a constant level of congestion over a period of time for all the travelers, the bottleneck model can capture such features as varying congestion over time and travelers' response to congestion tolls by adjusting departure time. However, except for the case of a single dominant player, the Vickrey-type bottleneck model would only fit the cases where users of a congestible facility are all "atomistic" (such as cars on highways). Airport terminals face individual passengers who are by definition atomistic and so won't take into account other passengers when making decisions. As a consequence, it appears to be a perfect context for the usage of the bottleneck model. Runways, on the other hand, face airplanes operated by a few large airlines that potentially internalize the congestion they impose on their own flights. Therefore, the bottleneck model may not be a good fit for runway congestion.[3] Our integrated model is related to D'Alfonso et al. (2013) but here we treat the two kinds of congestion explicitly and separately. Instead of assuming all passengers incur the same amount of terminal dwell time, which is roughly determined by the overall passenger volume at the airport, this new modeling approach enables the terminal dwell time to be elicited by individual passengers' airport arrival behavior, which is affected by both the number of passengers and the passenger types. Another difference with D'Alfonso et al. (2013) is that the present paper no longer assumes away airline price discrimination from the analysis.

We find that contrary to Czerny and Zhang (2011, 2014b), when terminal congestion is taken into account, uniform airfare *does not* yield the first-best outcome. This is because some passengers may prefer arriving at the airport far in advance to avoid long queues at check-in and security screening, while others may prefer arriving at the airport relatively late to avoid long dwell times before boarding. Intuitively, adding a passenger who arrives at the airport at a particular time may increase the queuing time for those arriving after that passenger and the airside dwell time for those arriving before by pushing their arrival times forward. As a result, different passengers cause different externalities on the others. Thus, the amount of terminal externality to

[1] See Zhang and Czerny (2012) and Basso and Zhang (2007) for recent surveys of these and other studies. For early congestion pricing studies see, for example, Levine (1969), Carlin and Park (1970), Morrison (1983), and Mohring (1999).

[2] A number of early papers have focused only on runway congestion, arising from the "all the flights leave at 8 a.m." phenomenon and/or the flight banking phenomenon (see further discussion in Section 2). Such clustering schedule behavior by airlines could however also lead to congestion at the pre-departure procedures at the terminal. In addition, the stringent new security requirements that were implemented as a direct result of the September 11th terrorist attacks have made such pre-departure procedures more cumbersome and time-consuming (an effect often referred to as the "hassle factor," see Ito and Lee 2005). Together, they make terminal congestion often a non-negligible matter (e.g., Appold and Kasarda, 2007; Saraswati and Hanaoka, 2012; Lin and Chen, 2013).

[3] The Vickrey bottleneck model was recently successfully applied to runway congestion with airlines having market power (e.g. Daniel, 1995, 2009; Silva et al., 2014). Such model setting includes only one dominant airline plus one or more atomistic fringe airline(s). Nevertheless, this model has difficulties in describing airports' dynamic congestion when two or more airlines have significant market shares – but such an oligopoly market structure is quite common in the industry (e.g., Morrison and Winston, 1989; Brander and Zhang, 1990, 1993; Zhang and Czerny, 2012). As indicated by Silva et al. (2014), the Vickrey model may not possess pure-strategy Nash equilibrium when it is applied in the Cournot oligopoly case. Silva, Lindsey, de Palma and van den Berg (2014) confirmed, in a duopoly setting, that with the Vickrey congestion technology either a pure strategy equilibrium does not exist or it exits while no queue occurs. Thus, the Vickrey bottleneck model may not be a good fit for runway congestion when the airport is served by several significant airlines. Verhoef and Silva (2015) describe the dynamic congestion pattern at airports served by two non-atomistic airlines by replacing bottleneck congestion with Chu (1995)'s flow congestion which ignores interactions among travellers departing at different time instants. Verhoef and Silva's work provides a possible alternative in modeling dynamic runway congestion in the future. More remarks on the relevance of road bottleneck models to the present setting will be given in the text.