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# Modeling airport capacity choice with real options

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ABSTRACT

This study models airport capacity choice when a real option for expansion can be purchased. Facing demand uncertainty, an airport first determines the capacity for immediate investment (the prior capacity) and the size of the land or other resources to be reserved for possible future expansion (the reserve). Once demand is observed, the airport can use a portion of the reserve to build extra capacity and set airport charge. Our analytical results show that if demand uncertainty is low and capacity and reserve costs are relatively high, an airport will not acquire a real option for expansion. Otherwise, it can use an expansion option to improve its expected profit or social welfare. Both the magnitude of profit or welfare gain and the optimal size of the reserve increase with demand uncertainty. A higher reserve cost leads to a larger prior capacity and a smaller reserve, whereas a higher capital cost leads to lower prior capacity. A profit-maximizing airport would choose a smaller prior capacity and reserve than would a welfare-maximizing airport. Competition within the airline market promotes airport capacity investment and the adoption of real options by profit-maximizing airports, whereas airport commercial services increase prior capacity but not the reserve.



## 1. Introduction

Airport capacity investment is lumpy and requires a lengthy planning and construction process. Moreover, the investment decision is made facing significant demand uncertainty (De Neufville and Barber, 1991; Maldonaldo, 1990; Oum and Zhang, 1990). As a result, capacity at many airports is either under- or over-invested,[1] and non-optimal airport capacity leads to huge social welfare losses (De Neufville and Odoni, 2003). In this paper, we show that airports can use real options to improve the efficiency of their capacity investments, and we discuss the economic and policy implications of applying real options to airport capacity investment.

This paper is motivated by the business strategies adopted by airports to deal with demand uncertainty in making investment decisions. Under one strategy, nearby land is reserved for possible future expansion, a practice called “land banking.”

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[1] The Montreal Mirabel Airport, new Denver International Airport, and Kansai International Airport are examples of over-investment that led to capacity under-use, either in the short and/or long term. The Newark airport in New York also experienced extended periods of under-use (De Neufville and Odoni 2003). The Amsterdam Schiphol Airport and Hong Kong International Airport (Chek Lap Kok) are examples of under-investment that led to capacity shortages much earlier than expected.

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For example, UPS worked with Louisville airport to secure space for the future expansion of its WorldPort sorting center. In another example, Seoul Inchon airport had only two runways when it opened, but large areas of land were reserved for possible future expansion to a maximum of five runways. Due to an increase in traffic, part of the reserved land has already been converted to capacity. Taipei Taoyuan International Airport also reserved nearby farmland for extended periods before designating it for airport expansion in 2011.

Another strategy used by airports incorporates flexible design into operations and planning. Flexible designs allow airports to adjust their capacity under new circumstances. For example, the Hong Kong International Airport adopted a self-propelled intra-airport passenger transport system which cost more than a cable-driven system at low traffic volume but provided long-term flexibility for capacity expansion. These strategies, land banking and flexible design, are applications of "real options" in airport capacity planning (Transportation Research Board (TRB) 2012).[2] By making investments at an early stage, real options provide the right, but not the obligation, to take certain courses of action at later stages when more information becomes available. Driouchi et al. (2012) point out that the main essence of real options is that they confer on their owners the ability to partly reverse commitments and to postpone decision-making until additional information is available.

Motivated by these business strategies, we build a model for airport capacity investment and investigate the effect that real options for expansion have on consumer surplus and the profits of airlines and airports. The real option in our paper is modeled as the land or other resources reserved for possible future airport capacity expansion, although the conclusions should hold for other real option applications. The built model has the following key features. First, capacity investment at an airport follows a multi-stage decision process: the airport first determines the initial capacity (prior capacity) and the size of the land or other resources reserved for possible future expansion (the reserve), and then uses a portion of the reserve to add incremental capacity given the realization of random demand. Second, the model incorporates airports' pricing decisions. Airport charges are made after the total capacity (prior capacity plus incremental capacity) is invested. Third, we consider both welfare-maximizing and profit-maximizing airports, which serve as benchmark cases to model the effect of airport ownership. Finally, airline competition is explicitly modeled, accounting for the vertical relationship between airlines and airports. Airlines engage in Cournot competition given an airport's capacity and charges, and the equilibrium outcomes from airline competition determine the traffic volume of the airport.

This paper is related to three broad streams of literature: that on modeling airport capacity investment, that on the effects of demand uncertainty on capacity choice and pricing in transportation sectors, and that on using real options in transport infrastructure investment. Studies modeling airport capacity investment mostly consider deterministic demand.[3] A few studies model the effects of demand uncertainty on managing airport congestion (Czerny, 2008, 2010), highway pricing and capacity choice (D' Ouville and McDonald, 1990; Kraus, 1982) and congestible infrastructure in general (Basso and Zhang, 2007; Proost and Van der Loo, 2010). Contrary to these papers in which capacity and price are determined simultaneously, we explicitly account for large sunk costs and long project cycles in airport capacity investment by extending the analytical model of Xiao et al. (2013). In this model, airport capacity investment and pricing are viewed as sequential decisions. Demand uncertainty matters especially for investment decisions when sunk costs are high and project cycles are long, as they are in airport capacity investment. Lumpy investments and long project cycles make real options valuable tools for airports to use in effectively investing.

The application of real options to transportation sectors has been studied under the modeling framework of Dixit and Pindyck (1994).[4] These studies focus on the valuation and pricing of real options, and the choice of timing given the possibility of deferred investments. The study most related to our paper is Smit's (2003), which analyzes optimal airport investment when an airport's future free cash-flow is uncertain. Heuristic solutions and numerical simulations are used to draw conclusions under very specific market conditions. In comparison, our paper focuses on the effects real options have on the efficiency of airports with different objectives (welfare maximizing vs. profit maximizing), and the policy implications for government regulation when airports use real options in their capacity investments. As such, our model allows us to draw clear insights from analytical results.

We find that if demand uncertainty is low and capacity and reserve costs are relatively high, an airport will not acquire a real option for expansion. Otherwise, an airport can use an expansion option to improve its expected profit or social welfare. Both the magnitude of profit or welfare gain and the optimal size of the reserve increase with demand uncertainty. A higher reserve cost leads to a larger prior capacity and a smaller reserve, whereas a higher capital cost leads to lower prior capacity. A profit-maximizing airport would choose a smaller prior capacity and reserve than a welfare-maximizing airport would. Competition within the airline market promotes airport capacity investment and the adoption of real options

[2] Applications of real options in airport capacity planning identified in the TRB report include land banking, reservation of terminal space, modular or incremental development, linear terminal design and centralized processing facilities, swing gates or spaces, non-load-bearing or glass walls and self-propelled people movers.

[3] Examples of these studies include Zhang and Zhang (2003), Oum et al. (2004), Forsyth (2005, 2007), Basso and Zhang (2007, 2008), Zhang and Zhang (2010), Zhang (2010).

[4] Examples of these studies include De Neufville (2003, 2008), Law et al. (2004), Chambers (2007), Martins (2013), Martins et al. (2014), Morgado et al. (2013), Gao and Driouchi (2013), Galera and Soliño (2010), Chow and Regan (2011a,2011b) and Smit (2003). For discussions of real options analysis and decision making in general, see Trigeorgis (1993, 1996), Driouchi and Bennett (2012), Driouchi et al. (2010), Chevalier-Roignant et al. (2011), and Trigeorgis and Reuer (2017).