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Airport capacity choice under airport-airline vertical arrangements

By
Yibin Xiao[1], Xiaowen Fu and Anming Zhang[3]

[1] The University of Electronic Science and Technology of China
[3] The Sauder School of Business, University of British Columbia

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ABSTRACT: This study investigates the effects of airport-airline vertical arrangements on airport capacity choices under demand uncertainty. A multi-stage game is analyzed, in which competing airlines contribute to capacity investments and at the same time share airport revenues. Our analytical results suggest that for a profit-maximizing airport, such a vertical arrangement leads to higher capacity although its profit may not be higher. For a welfare-maximizing airport, such an arrangement has no effect on capacity or welfare. Capital cost savings brought by airport-airline cooperation, if any, always leads to higher capacity, higher profit for a profit-maximizing airport, and higher welfare in the case of a welfare-maximizing airport. Numerical simulations reveal that win-win outcomes may be achieved for an airport and its airlines without government intervention.

KEY WORDS: ***Airport Capacity; Airport-airline Vertical Arrangement; Demand Uncertainty Keywords***

AUTHORS: **Xiao; Fu and Zhang**

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CONTACT: INSTITUTE OF TRANSPORT AND LOGISTICS STUDIES (C13)

The Australian Key Centre in Transport and Logistics Management

The University of Sydney NSW 2006 Australia

Telephone: +612 9114 1824

E-mail: business.itlsinfo@sydney.edu.au

Internet: http://sydney.edu.au/business/itls

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1. Introduction

Due to strong growth in traffic volumes, an increasing number of airports are approaching their capacity limits. Unless timely investments on infrastructure are made, serious delays and congestions will threaten the long-term development of the aviation industry. The Airports Council International (ACI 2013) estimates that in the United States alone, airports' capital need for 2013 through 2017 is $71.3 billion or $14.3 billion per year. Among the investment needed, 54% is intended to accommodate growth in passenger and cargo as well as larger aircraft, with the rest planned for the maintenance and rehabilitation of existing infrastructure. However, federal funding schemes, such as the Airport Improvement Program (AIP) and the Passenger Facility Charges (PFCs), are insufficient for such investment requirements. The Transportation Research Board (TRB 2007) estimated that during the 2001-2004 period, only 21% and 11% of airports' capital were from AIP and PFC, respectively (see Zhang 2012 for discussion of changes in AIP and PFCs over time). In other markets, with the trend of privatization and commercialization, an increasing number of airports are now free from government subsidy or financial assistance, and turn to alternative financing options and revenue sources. Since airport investments are often lumpy (Oum and Zhang 1990), retained earnings are usually not sufficient. Many airports have chosen to work with airlines through various types of vertical arrangements (Fu et al. 2011).

Airlines can contribute to airport capacity expansion in several ways, including direct/joint investments in infrastructure, or sharing financial risks so that the airport can bring in loans and reduce capital costs. For example, terminal 2 of Munich Airport is jointly invested by the airport operating company FMG (60%) and Lufthansa (40%). Profits generated from the terminal are shared by the two investors. Lufthansa has also been investing in Frankfurt Airport, and holds 29% share of Shanghai Pudong International Airport Cargo Terminal (Fu and Zhang, 2010). The Los Angeles International Airport is undergoing a $1.4 billion upgrade to be completed by 2016, in which Southwest Airlines is investing $400 million in terminal concourse, ticketing and baggage claim areas, security, and gate reorganizations. American, Delta, and United are also contributing $33 million, $229 million, and $412 million respectively for various projects.[1]

In other cases, airlines contribute to infrastructure investments by sharing financial risks and thereby helping airports get loans at competitive interest rates. Airports and airlines enter into use-and-lease

[1] Information summarized at FlightGlobal, http://www.flightglobal.com/blogs/airline-business/2014/01/domestic-terminal-developments-lax/. Similar arrangements can be observed in many other airports. For example, Southwest is investing $156 million to build the first international terminal and surrounding infrastructure at Houston Hobby Airport, which are to be completed in 2015. In other cases, a group of airlines may jointly invest in airport facilities. For example, twenty airlines formed SeaTac Fuel in 2000, which effectively monopolizes fuelling services at the Seattle-Tacoma International Airport. Vancouver Airport Fuel Facilities Corporation (VAFFC) is owned by a consortium of commercial airlines serving the airport, and is planning to invest up to $100 million on a major expansion project to enhance its fuelling capacity.

contracts that specify the terms of and payment for airport facilities. The US Federal Aviation Administration (FAA 1999) notes that these agreements often form the foundation for airport financing, and can be grouped into three categories: compensatory, residual, and hybrid. Under a residual agreement, a carrier who signed the master use-and-lease agreement is awarded the so-called "signatory airline" status. These carriers pledge to pay any costs of operating the airport that are not allocated to non-signatory airlines or covered by non-aviation revenues. This allows an airport to transfer financial risks to its signatory carriers.[2] Many airports finance infrastructures by issuing revenue bonds. Residual agreements are often structured to provide bond investors with increased security, and accordingly, the terms of these contracts are usually longer than compensatory agreements. Since an airport is usually served by many signatory airlines, financial failures of individual carriers do not lead to disastrous outcomes to the airport. The US Department of Transportation (DOT 2003) noted that since the deregulation in 1978, more than 130 airlines filed for bankruptcy yet no airport revenue bond has defaulted. With financial risks reduced, many airports are able to finance investments at competitive rates.

Airport bonds have become a major source of capital for the industry. By 1995, a total of $4.52 billion had been raised for the construction of the Denver International Airport, 76.5% of which was through airport revenue bonds (DIA 2014). Large airports tend to use bonds more extensively. During the 1990s, general airport revenue bonds (GARBs) accounted for 36-70% of capital expenditures for US airports, or over $3 billion per year on average (FAA 1999). Bond issuance reached its peak in 2010, totaling $17.3 billion in revenue bonds and $1.2 billion in issuance for airline special facility bonds (DIA 2014).[3] Service and financial commitments by signatory airlines are important determinants of bond ratings and yields. Airline-Airport Lease and Use Agreements (ALUA) are legally binding contracts specifying airlines' obligations. When issuing airport facilities bonds in 2012, the Greater Orlando Aviation Authority (GOAA) revealed that even if a signatory airline is under bankruptcy protection and decides to reject the ALUA, the carrier is liable for the amounts unpaid prior to bankruptcy plus the greater of i) one year of rent or ii) 15% of the total remaining lease payments, not to exceed three years (GOAA 2012).

In return for the investments committed and risks borne, signatory airlines are given varying degrees of influence over airport planning, operations and capital investments, and sometimes exclusive or

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[2] In comparison, under a compensatory agreement, an airport charges its airline tenants fees and rental charges in an amount necessary to recover actual cost. Accordingly the airport assumes the financial risk of any overall revenue shortfall. Hybrid agreements combine elements of both the compensatory and residual agreements (FAA 1999).

[3] The Transportation Research Board (TRB 2007) defines four basic types of bonds that are issued to fund airport capital improvements, including i) general obligation bonds supported by the overall tax base of the issuing entity (the airport sponsor); ii) GARBs secured by the revenues of the airport and other revenues as may be defined in the bond indenture; iii) bonds backed either solely by PFC revenues or by PFC revenues and airport revenues generated by rentals, fees, and charges; and iv) special facility bonds backed solely by revenues from a facility constructed with proceeds of those bonds.

preferential facility use (Fu et al. 2010). Airport capital expenditures have to be approved by signatory airlines, except for projects required by a governmental authority (e.g. the FAA, the DOT), or facilities for which the tenants or users will be required to pay directly. Signatory airlines also receive various financial benefits. They often pay lower charges than non-signatory airlines under a residual agreement. In many cases, they also share proportions of airport revenue. The ALUA of the greater Orlando aviation authority entitles signatory airlines to share net revenues after the payment of debt and other fund requirements. In fiscal years 2009 and 2010, 70% and 30% of net revenues were divided between the airport and signatory airlines, respectively (GOAA 2012). Revenue sharing arrangements have also been used in airports such as Tampa, Charleroi and Munich, among others (Fu and Zhang 2010).

In summary, airlines can contribute to airport capacity through direct/joint investments, or to share financial risks thus that airports can finance projects with reduced capital costs. In return, signatory airlines are given varying degrees of influence over airport operations, capacity investments, and resource allocation. They may also be compensated financially, either through revenue sharing, or indirectly through discounted airport charges or preferential facility use. Airlines now play important roles in airport investments. AMR Corp., the parent company of American Airlines, alone had $3.2 billion of debt backing airport facilities as of 2011.[4]

In recent years, airlines' involvements in airport operation and development have attracted considerable regulatory attention, yet no consensus has been reached on the optimal policy towards airport-airline vertical arrangements. The FAA expressed concerns over favorable terms offered by an airport to a particular airline, because this may harm competition in the downstream airline markets (FAA 1999). Andreas Kopp, the chief economist of OECD/ECMT (Organisation for Economic Co-operation and Development / The European Conference of Ministers of Transport) claimed that market power creates rents to an airport and dominant airline(s). He argued that airline dominance "is bound to lead to under-investment in airport capacity. As (private or public) airport developers do not receive the full marginal value product of airport investment, due to the sharing of rents with dominant airlines, they will tend to under-invest in airport capacity" (ECMT 2003). This argument, however, has not recognized the possibility that airline cooperation and commitments may reduce airports' capital costs. In addition, although airport capacity limit may help dominant airlines to achieve higher yields, it also prevents hub carriers from developing extensive hub-and-spoke networks. Therefore, an airline's preference for airport expansion may be dependent on market conditions, as evidenced by mixed observations in the aviation industry. The US Department of Transport (DOT 2001) concluded that "to the extent dominant hub carriers have market power, they can not only charge higher prices, but also control capacity, keep it at a lower level than would prevail in a competitive market." Dresner et al. (2002) found that the lack of airport capacity may form entry barriers to airlines who wish to initiate services. On the other hand, there are many cases in which hub carriers support airport capacity expansion. British Airways and Cathay Pacific, for example,

[4] Bloomberg report "AMR-Backed Municipal Airport Debt Falls on American Air Parent Bankruptcy", http://www.bloomberg.com/news/2011-11-29/amr-backed-municipal-airport-debt-falls-on-american-air-parent-bankruptcy.html

supported capacity expansion projects in Heathrow Airport and Hong Kong International Airport, respectively. Rod Eddington, Chief Executive of British Airways, stated that "British Airways' development as a global network carrier has underpinned the success of the British aviation industry and the lack of capacity at Heathrow hits us hard" (Eddington 2003). In general, the effects of airport-airline vertical arrangements on airport capacity remain unclear.

Quite a few economic studies examined investments on airport infrastructures (see, for example, Zhang and Zhang 2003, 2006, 2010, Oum et al. 2004, Forsyth 2005, 2007, Basso and Zhang 2007a, Zhang 2010). However, airport-airline arrangements have not been explicitly considered in capacity choices, and no study has formally modeled possible savings in airport capital costs brought by airline cooperation. The emerging literature on airport-airline vertical arrangements has mostly focused on airline competition and traffic volumes (see, for example, Fu and Zhang 2010, Zhang et al. 2010, Barbot 2009, 2011, Barbot et al. 2013, D'Alfonso and Nastasi 2012, D'Alfonso et al. 2013, Sarmento and Brandao 2013), risk sharing between an airport and its airlines (Hihara 2011, 2012, Starkie 2012, D'Alfonso and Nastasi 2012), factors influencing the formation of such arrangements (Yang et al. 2014), and forms of vertical arrangements (Starkie 2008, Fu et al. 2010).[5] Therefore, these studies do not directly examine the effects and mechanisms through which airlines influence airport capacity. In particular, Yang et al. (2014) analyze airport-airline revenue sharing in a bargaining game. Their analytical results suggest that when an airport cannot make an exclusive arrangement with one airline and when lump-sum payments cannot be arranged, the airport and airlines cannot mutually benefit at the same time. Such results however cannot fully explain the increased use of vertical arrangements in the aviation industry. Complementary results may be obtained by developing models that incorporate capital cost savings brought by airport-airline cooperation, and airlines' influence on airport capacity choice.

Another recent area of research is the treatment of demand uncertainty in airport capacity choice. Empirical investigations have shown that there is substantial volatility in airport traffic volumes (e.g., Maldonaldo 1990, De Neufville and Barber 1991), and significant forecast biases are present even at national level (De Neufville and Odoni, 2003). However, only a few economic studies have formally modeled such uncertainty. Xiao et al. (2013) analyze the effects of demand uncertainty on airport capacity choices, and conclude that uncertainty will not change capacity choice if demand variation is low and capacity cost is high; otherwise the optimal airport capacity under demand uncertainty will be larger than the case when a deterministic mean demand is considered.

The present study aims to make both methodological and policy contributions to the literature. To the best of our knowledge, it is the first study that simultaneously considers airport-airline vertical arrangements, airline competition, and airport capacity choice in the presence of demand uncertainty.[6]

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[5] See D'Alfonso and Nastasi (2014) for a recent survey of the literature. For comprehensive literature surveys on airport pricing and capacity investment using a "vertical structure" approach, see Basso and Zhang (2007b) and Zhang and Czerny (2012).

[6] Although Sarmento and Brandao (2013) examined the effects of airport-airline profit sharing on a (profit-

Such an approach allows us to investigate the interactions of airports and airlines in an integrated model, and their implications to airport capacity and social welfare. Modeling results from such a study will offer valuable insights into the debates over such important policy questions as: What is dominant airlines' preference over airport capacity investments; When can airport-airline vertical arrangements facilitate airport expansion; Whether can airports and airlines achieve win-win outcomes that are also welfare-improving; or does government regulation have to be introduced to achieve Pareto improvements? These questions are investigated through a multistage game, in which an airport chooses its capacity given the vertical arrangements with its signatory airlines in the presence of demand uncertainty, and the airport may maximize its profit or social welfare.

The rest of the paper is organized as follows. Section 2 introduces the basic economic model. Section 3 and Section 4 analyze the cases of a profit-maximizing airport and a welfare-maximizing airport, respectively. The last section summarizes and concludes this study.

2. The Model

We consider an airport served by two signatory airlines, say airline 1 and 2. These two airlines provide homogenous services at the airport, and have identical constant marginal cost c. Using a similar specification as in Xiao et al. (2013), the inverse demand function of airlines is

$$P = X - bQ \quad (b > 0) \quad , \tag{1}$$

where P is airfare paid by passengers, $Q = q_1 + q_2$ is total traffic volume at the airport, and X is a random variable that captures the demand forecast's margin of error. Let $f(x)$ be the density function of X, and $F(x)$ be the corresponding distribution function. For modeling tractability, X is assumed to follow a uniform distribution in the interval $(\underline{x}, \overline{x})$, and so $f(x) = 1/(\overline{x} - \underline{x})$. Airlines have reached an agreement with the airport, thus that each signatory airline contributes a proportion s of the capital needed for airport capacity investment, and in exchange shares a proportion s of the airport's revenue. That is, the airport and airlines may be regarded as partners in a joint venture for capacity investment. Commitments from signatory airlines reduce the risk of capacity investment, and so capital cost is reduced by δ per cent. On average, the airport derives a profit h from commercial services per passenger and the associated consumer surplus is v. Both h and v are assumed to be positive and exogenously determined.[7]

The airport and airlines' behavior is modeled as a multi-stage game:

- Stage 1: The airport decides the capacity, K, to be invested based on the distribution of demand shifter $f(x)$. With discounted capital cost $(1-\delta)r$, the cost of airport capacity is

maximizing) airport's incentives to invest, the investment did not specifically refer to capacity investment, nor was airport demand uncertainty considered in their analysis.

[7] For alternative modeling of concession services, see Czerny (2006, 2013) and Yang and Zhang (2011).

$(1-\delta)rK$.

- Stage 2: Conditional on the capacity installed and the observed demand *x*, the airport sets its service charge ω.
- Stage 3: The airlines compete in Cournot fashion to maximize their respective profits.

To solve for the optimal capacity *K*, we first consider Stage 3, in which the objective of signatory airline *i* (*i* = 1,2) is specified as follows:

$$\max_{q_i} \pi_i \,|x, \omega, K = (P - c - \omega)q_i + s[(\omega + h)Q - (1-\delta)rK] \quad (2)$$
$$\text{s.t.} \quad 0 \le \mathrm{Q} = q_1 + q_2 \le K, \quad i = 1\,,2\,.$$

The corresponding Lagrangian function with multipliers μ_i and λ_i can be specified as $L_i(q_i, u_i, \lambda_i) = (P - c - \omega)q_i + s\big((w+h)Q - (1-\delta)rK\big) + \mu_i Q - \lambda_i(Q - K)$, which leads to following first-order condition (FOC)

$$\frac{\partial L_i(q_i, u_i, \lambda_i)}{\partial q_i} = X - bQ - bq_i - c - (1-s)\omega + \mathrm{sh} + \mu_i - \lambda_i = 0,\; i = 1{,}2. \quad (3)$$

Equilibrium results can be obtained depending on whether capacity constraints are binding.

Case 1. If capacity constraint $\mathrm{Q} \ge 0$ in eq. (2) is binding, then $q_\mathrm{i} = 0$, $\lambda_i = 0$, and $\mu_i \ge 0$. With eq. (3) we have

$$\mu_i = -(\mathrm{x} - \mathrm{c} - (1-\mathrm{s})\omega + \mathrm{sh}) \ge 0 \;\; \rightarrow \; \omega \ge \frac{1}{1-s}(x - c + sh). \quad (4)$$

This corresponds to the extreme case when airport charge is so high that airlines leave the market, and thus airport's traffic volume at equilibrium is $Q_1^* = 0$.

Case 2. If capacity constraint $\mathrm{Q} \le \mathrm{K}$ is binding, then $\mathrm{Q} = \mathrm{K}$, $\lambda_i \ge 0$, and $\mu_i = 0$. Moreover, the symmetry of airlines implies that their outputs are the same, or $q_\mathrm{i} = \frac{K}{2}$. The associated FOC implies that

$$\lambda_i = x - \frac{3}{2}bK - c - (1-s)\omega + sh \ge 0 \quad \rightarrow \quad \omega \le \frac{1}{1-s}\Big(x - c + sh - \frac{3}{2}bK\Big). \quad (5)$$

In this case, the airport's service charge is low and demand is high. Airport capacity is fully utilized, and so traffic volume at equilibrium is $Q_2^* = K$

Case 3. If neither capacity constraint is binding, or $0 < \mathrm{Q} < K$ and $\mu_i = \lambda_i = 0$, with airlines symmetry and associated FOCs, the output of each airline can be obtained as

$$q_1 = q_2 = \frac{1}{3b}(x - c - (1-s)\omega + sh). \quad (6)$$

The condition $0 < \mathrm{Q} < K$ implies that

$$\frac{1}{1-s}\left(x-c+sh-\frac{3}{2}bK\right)<\omega<\frac{1}{1-s}(x-c+sh). \quad (7)$$

This corresponds to the case when the airport's service charge is neither too low nor too high with respect to the actual demand observed, and the invested capacity is partially utilized. It can be derived that the total traffic volume at the airport is $Q_3^*=\frac{2}{3b}(x-c-(1-s)\omega+sh)$.

The solutions for Stage 3 will be used repeatedly in the following sections, and are summarized in the following proposition 1.

Proposition 1: *Conditional on airport capacity K, airport service charge ω, and observed demand level x,*

i. *if the airport charge is too high relative to travel demand, in the sense that* $\omega \geq \frac{1}{1-s}(x-c+sh)$ *in our model, signatory airlines will stay away from the market thus* $Q^*=0$ *, and airlines' profits equal zero* $\pi_i^*=0$ *,* $i=1,2$ *.*

ii. *if the airport charge is quite low relative to travel demand, in the sense that* $\omega \leq \frac{1}{1-s}(x-c+sh-\frac{3}{2}bK)$ *in our model, airport capacity is fully utilized and* $Q^*=Q_2^*=K$*. The profit of airline i* $(i=1,2)$ *is*

$$\pi_i^*=\frac{(x-bQ_2^*-c-\omega)Q_2^*}{2}+s\big((\omega+h)Q_2^*-(1-\delta)rK\big) \quad (8)$$

iii. *if relative to travel demand, the airport charge is neither too low nor too high in the sense that* $\frac{1}{1-s}(x-c+sh-\frac{3}{2}bK)<\omega<\frac{1}{1-s}(x-c+sh)$ *in our model, the airport capacity is partially utilized and* $Q=Q_3^*=\frac{2}{3b}(x-c-(1-s)\omega+sh)$*, The profit of airline i* $(i=1,2)$ *is*

$$\pi_i^*=\frac{(x-bQ_3^*-c-\omega)Q_3^*}{2}+s\big((\omega+h)Q_3^*-(1-\delta)rK\big) \quad (9)$$

3. Decisions of a Profit-Maximizing Airport

This section considers the price and capacity decisions made by a profit-maximizing airport. In Stage 2 of our three-stage game, the airport chooses its service charge ω to maximize its profit, given the airport capacity and observed demand level. Its decision problem can be specified as

$$\max_{\omega} \Pi|x,K=(1-2s)[(\omega+h)Q-(1-\delta)rK] \quad (10)$$

By Proposition 1, the airport's profit conditional on capacity invested K and observed demand x can be further specified as follows, where Q_3^* is the airport traffic volume (i.e. derived demand) defined in the proposition.

$$\Pi|x,K = \begin{cases} -(1-2s)(1-\delta)rK & \text{when} \quad \omega \geq \frac{1}{1-s}(x-c+sh) \\ (1-2s)\left[\left((\omega+h)K-(1-\delta)rK\right)\right] & \text{when} \quad \omega \leq \frac{1}{1-s}\left(x-c+sh-\frac{3}{2}bK\right) \\ (1-2s)\left[\left((\omega+h)Q_3^*-(1-\delta)rK\right)\right] & \\ & \text{when} \quad \omega \in \left(\frac{1}{1-s}(x-c+sh-\frac{3}{2}bK), \frac{1}{1-s}(x-c+sh)\right) \end{cases} \tag{11}$$

To focus on non-trivial solutions, it is assumed that $\underline{x} > c - \mathrm{h}$, so that positive traffic volume is possible when the demand shifter takes the lowest possible value. The FOCs of the airport's profit maximization problem lead to the following conclusions:

Proposition 2: *Conditional on airport capacity K, the optimal airport charge of a profit-maximizing airport can be determined as follows (subscript "p" denoting profit-maximization):*

(i) *If $x \geq c - h + 3bK$, the airport's maximum profit $\Pi_p^* = \Pi_{p,2}^*$ is achieved when its service charge is set as*

$$\omega_p^* = \omega_{p,2}^* = \frac{1}{1-s}\left(x - c + sh - \frac{3}{2}bK\right) \tag{12}$$

(ii) *Otherwise if $x < c - h + 3bK$, the airport's maximum profit $\Pi_p^* = \Pi_{p,3}^*$ is achieved when its service charge is set as*

$$\omega_p^* = \omega_{p,3}^* = \frac{1}{2(1-s)}(x - c + (2s-1)h) \tag{13}$$

Now consider the airport's decision in Stage 1, when it maximizes its expected profit by choosing capacity based on the probability distribution of future demand:

$$\max_K \ E\Pi = E\,(1-2s)[(\omega+h)Q - (1-\delta)rK] \tag{14}$$

where Q and ω are the derived demand of the airport in Stage 3 and its optimal charge in Stage 2, respectively. For ease of notation, two critical values are defined

$$K_{CV1}^p = \frac{1}{3b}\left(\underline{x} - c + h\right) \tag{15.1}$$

$$K_{CV2}^p = \frac{1}{3b}(\overline{x} - c + h) \tag{15.2}$$

Then the expected profit can be further specified as:

Case I. If $K \geq K_{CV2}^p$ which implies $\overline{x} \leq c - h + 3bK$, the expected profit of the airport is $\mathrm{E}\Pi = \int_{\underline{x}}^{\overline{x}} \Pi_{\mathrm{p},3}^* f(x)dx$. It can be shown that $\frac{d}{dK}\mathrm{E}\Pi = -(1-\mathrm{s})(1-\delta)\mathrm{r} < 0$, and thus the optimal capacity is

$$K_p^* = K_{p,1}^* = \frac{1}{3b}(\overline{x} - c + h) \tag{16}$$

Case II. If $K \leq K_{CV1}^p$ which implies $\underline{x} \leq c - h + 3bK$, the expected profit is $\mathrm{E\Pi} = \int_{\underline{x}}^{\overline{x}} \Pi_{\mathrm{p},2}^* f(x)dx$. By the first-order condition $\frac{d}{dK}\mathrm{E\Pi} = 0$ the following results can be obtained:

(II.a) if $\mathrm{r} > \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$, the airport does not invest any capacity, i.e.,

$$K_p^* = K_{p,1}^* = 0 \tag{17}$$

(II.b) if $\frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)} \leq r \leq \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$, the optimal airport capacity is

$$K_p^* = K_{p,2}^* = \frac{1}{3b}\left[\frac{\overline{x}+\underline{x}}{2} - c + h - (1-s)(1-\delta)r\right] \tag{18}$$

(II.c) if $\mathrm{r} < \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$, the optimal airport capacity is

$$K_p^* = K_{p,2}^* = \frac{1}{3b}\left(\underline{x} - c + h\right) \tag{19}$$

Case III. If $K_{CV1}^p < K < K_{CV2}^p$, which implies that $\underline{x} < c - h + 3bK < \overline{x}$, the expected profit is $\mathrm{E\Pi} = \int_{\underline{x}}^{\hat{x}} \Pi_{\mathrm{p},3}^* f(x)dx + \int_{\hat{x}}^{\overline{x}} \Pi_{\mathrm{p},2}^* f(x)dx$, where $\hat{x} = c - h + 3bK$. By the first-order condition $\frac{d}{dK}\mathrm{E\Pi} = 0$ it can be derived that if $\mathrm{r} < \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$, the optimal airport capacity is

$$K_p^* = K_{p,3}^* = \frac{1}{3b}\left(\overline{x} - c + h - \sqrt{2r(1-s)(1-\delta)(\overline{x}-\underline{x})}\right) \tag{20}$$

Otherwise, there is no optimal capacity for the airport in this case.

Comparing the airport's profits across different cases, the optimal capacity can be obtained as in the following proposition.

Proposition 3: *For a profit-maximizing airport,*

(i) *if* $\mathrm{r} < \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$, *the optimal capacity is*

$$K_p^* = K_{p,3}^* = \frac{1}{3b}\left(\overline{x} - c + h - \sqrt{2r(1-s)(1-\delta)(\overline{x}-\underline{x})}\right) \tag{21}$$

(ii) *if* $\frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)} \leq r \leq \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$, *the optimal capacity is*

$$K_p^* = K_{p,2}^* = \frac{1}{3b}\left[\frac{\overline{x}+\underline{x}}{2} - c + h - (1-s)(1-\delta)r\right] \tag{22}$$

(iii) *if* $\mathrm{r} > \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$, *the optimal capacity is 0 (no capacity is invested).*

It is clear that the optimal capacity K_p^* of a profit-maximizing airport increases with both s and δ (i.e. $\frac{\partial K_p^*}{\partial s} \geq 0$ and $\frac{\partial K_p^*}{\partial \delta} \geq 0$, where equality is possible at border conditions). That is, vertical cooperation increases airport capacity. The airport does not receive the full marginal product of investment as pointed out by ECMT (2003). However, effective airport charges are reduced, which leads to higher outputs by signatory airlines. Saving in capital cost (i.e. δ) promotes capacity investments further, and improves the airport's profit too (i.e. $\frac{\partial \Pi_p^*}{\partial \delta} \geq 0$). The sign of $\frac{\partial \Pi_p^*}{\partial s}$ however depends on many parameters and cannot be determined. Intuitively, revenue sharing has a two-way effect on an airport's profit. On the one hand, it encourages airlines to produce more outputs. On the other hand, a lower proportion of profit will be left for the airport. The net effect on airport profit is thus dependent on market and other conditions.

The effect of demand uncertainty on capacity is intuitive. If capital cost is very high relative to travel demand ($r > \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$ in our model), the airport will not invest in any capacity. Otherwise, if capital cost is low relative to travel demand (in our model $r < \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$), the airport will invest in substantial capacity even if it may be partially utilized in the future. If capital cost is moderate (i.e. $\frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)} \leq r \leq \frac{\overline{x}+\underline{x}-2c+2h}{2(1-s)(1-\delta)}$), the same amount of capacity will be invested as in the case of a deterministic mean demand (i.e. when $x = (\overline{x} + \underline{x})/2$). The airport charge is set to the level when invested capacity is just fully utilized.

In the multistage game, the proportion of airline investment and shared revenue, s, is treated as a fixed value (exogenously given). However, it is unclear whether an airport and its airlines are willing to enter into the vertical arrangements at the first place. That is, it is unclear if an incentive-compatible agreement can be reached, or if win-win cooperation can be arranged between the airport and its airlines without intervention from a third party (e.g. government). Note that absent a vertical arrangement, $s = 0$ and $\delta = 0$. An incentive-compatible agreement may be reached if for both the airport and the airlines, their expected profits under such an agreement are higher than those without, or

$$\mathrm{E}\,\Pi_{\mathrm{p}}^*(s,\delta) - \mathrm{E}\,\Pi_{\mathrm{p}}^*(0,0) \geq 0 \tag{23.1}$$

$$\mathrm{E}\,\pi_{\mathrm{i,p}}^*(s,\delta) - \mathrm{E}\,\pi_{\mathrm{i,p}}^*(0,0) \geq 0, \qquad i = 1,2, \tag{23.2}$$

These profit functions have complex step-wise specifications which are conditional on capital cost and demand variability. For example, if $r < \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$, then

$$\mathrm{E}\,\pi_{\mathrm{i,p}}^*(s,\delta) =$$

$$\int_{\underline{x}}^{\hat{x}^*} \left[\frac{(x-bQ_3^*-c-\omega_{p,3}^*)Q_3^*}{2} + s\left(\left(\omega_{\mathrm{p},3}^* + h\right)Q_3^* - (1-\delta)rK_{p,3}^*\right)\right] f(x)dx + \int_{\hat{x}^*}^{\overline{x}} \left[\frac{(x-bQ_2^*-c-\omega_{p,2}^*)Q_2^*}{2} +\right.$$

$s\left(\left(\omega^*_{\mathrm{p},2}+h\right)Q_2^*-(1-\delta)rK^*_{p,3}\right)\Big]f(x)dx$,

where $\hat{x}^*=c-h+3bK^*_{p,3}$. Otherwise, if r $\geq \frac{\overline{x}-\underline{x}}{2(1-s)(1-\delta)}$, then

$$\mathrm{E}\ \pi^*_{\mathrm{i,p}}(s,\delta)=\int_{\underline{x}}^{\overline{x}}\left[\frac{\left(x-bQ_2^*-c-\omega^*_{p,2}\right)Q_2^*}{2}+s\left(\left(\omega^*_{\mathrm{p},2}+h\right)Q_2^*-(1-\delta)rK^*_{p,2}\right)\right]f(x)dx.$$

The closed-form solutions cannot be obtained even for some simplified special cases. We have carried extensive numerical simulations, which confirm that there are feasible values of *s* that satisfy eq. (23.1) and eq. (23.2) simultaneously. However, no clear relationship can be identified between *s* and other parameters such as *r* and δ, and the shapes of feasible areas are fairly sensitive to the values of other parameters. It seems that whether win-win arrangements can be reached between airports and airlines is conditional on particular market situations. Some of the simulation results are reported in the Appendix.

4. Decisions of a Welfare-Maximizing Airport

This section considers the price and capacity decisions by a welfare-maximizing airport. In Stage 2, conditional on the capacity invested *K*, social welfare is calculated as follows

$SW=$

$\int_0^Q P(y,X)dy-PQ+vQ+\sum_{i=1}^{2}\{(P-c-\omega)q_i+s\big((\omega+h)Q-(1-\delta)rK\big)\}+(1-$

$2s\omega+hQ-1-\delta rK$ (24)

Thus, the decision problem of the airport can be specified as

$$\max_{\omega} SW|x,K=-\frac{1}{2}bQ^2+(x+h+v-c)Q-(1-\delta)rK, \quad (25)$$

By Proposition 1, welfare can be calculated conditional on capacity invested *K* and observed demand *x* as in eq. (26), where Q_3^* is the airport traffic volume as defined in the proposition.

$$SW|x,K=\begin{cases}-(1-\delta)rK & \text{when } \omega\geq\frac{1}{1-s}(x-c+sh)\\ -\frac{1}{2}bK^2+(x+h+v-c)K-(1-\delta)rK & \text{when } \omega\leq\frac{1}{1-s}\left(x-c+sh-\frac{3}{2}bK\right)\\ -\frac{1}{2}bQ_3^{*2}+(x+h+v-c)Q_3^{*2}-(1-\delta)rK & \text{when}\\ & \omega\in\left(\frac{1}{1-s}\left(x-c+sh-\frac{3}{2}bK\right),\frac{1}{1-s}(x-c+sh)\right)\end{cases} \quad (26)$$

To focus on non-trivial solutions, it is assumed that $\underline{x}>c-h-v$, thus that positive traffic volume is possible even if the demand shifter takes the lowest possible value. The FOCs of eq. (25) lead to the following conclusions as summarized in Proposition 4:

Proposition 4: *Conditional on airport capacity K, the optimal airport charge of a welfare-maximizing airport can be determined as follows (subscript "w" for welfare-maximization):*

(i) *If* $x < c - h - v + bK$, *the airport's optimal service charge, and corresponding social welfare are*

$$\omega_w^* = \omega_{w,3}^* = -\frac{1}{2(1-s)}(x - c - 2sh + 3h + 3v), \tag{27}$$

$$SW_w^* = SW_{w,3}^* = \frac{1}{2b}(x + h + v - c)^2 - r(1-\delta)K. \tag{28}$$

(ii) *Otherwise if* $x \geq c - h - v + bK$, *any charge satisfying* $\omega_w^* \leq \frac{1}{(1-s)}\left(x - c - sh - \frac{3}{2}bK\right)$ *will lead to full utilization of airport capacity, and the following maximum welfare*

$$SW_\omega^* = SW_{\omega,2}^* = -\frac{1}{2}bK^2 + (x + h + v - c)K - (1-\delta)rK \tag{29}$$

Now consider the airport's decision in Stage 1, when it maximizes the expected welfare by choosing capacity based on the probability distribution of future demand:

$$\max_K \mathbf{E}\, SW = E\left[-\frac{1}{2}bQ^2 + (x + h + v - c)Q - (1-\delta)rK\right]. \tag{30}$$

For ease of notation, the following two critical values are defined

$$K_{CV1}^w = \frac{1}{b}\left(\underline{x} - c + h + v\right) \tag{31.1}$$

$$K_{CV2}^w = \frac{1}{b}(\overline{x} - c + h + v) \tag{31.2}$$

The optimal capacity of the welfare-maximizing airport can be derived as follows:

Case I. If $K \geq K_{CV2}^w$ which implies $\overline{x} \leq c - h + v + bK$, the expected welfare is $\mathrm{E}\, SW = \int_{\underline{x}}^{\overline{x}} \mathrm{SW}_{w,3}^* f(x)dx$. It can be shown that $\frac{d}{dK}E\ SW = -(1-\delta)r < 0$, and thus the optimal capacity is

$$K_w^* = K_{w,1}^* = K_{CV2}^w = \frac{1}{b}(\overline{x} - c + h + v) \tag{32}$$

Case II. If $K \geq K_{CV1}^w$ which implies $\underline{x} \geq c - h - v + bK$, the expected welfare is $E\ SW = \int_{\underline{x}}^{\overline{x}} \mathrm{SW}_{\omega,2}^* f(x)dx$. By the FOC $\frac{d}{dK}E\ SW = 0$, the following results can be obtained:

(II.a) if $r > \frac{\overline{x} + \underline{x} - 2c + 2h + 2v}{2(1-\delta)}$, the airport does not invest any capacity, or

$$K_w^* = K_{w,1}^* = 0 \tag{33}$$

(II.b) if $\frac{\overline{x} - \underline{x}}{2(1-\delta)} \leq r \leq \frac{\overline{x} + \underline{x} - 2c + 2h + 2v}{2(1-\delta)}$, the optimal airport capacity is

$$K_w^* = K_{w,2}^* = \frac{1}{b}\left[\frac{\overline{x}+\underline{x}}{2} - c + h + v - (1-\delta)r\right] \tag{34}$$

(II.c) if $r < \frac{\overline{x}-\underline{x}}{2(1-\delta)}$, the optimal airport capacity is

$$K_w^* = K_{w,2}^* = K_{CV1}^w = \frac{1}{b}\left(\underline{x} - c + h + v\right) \tag{35}$$

Case III. If $K_{CV1}^w < K < K_{CV2}^w$ which implies that $\underline{x} < c - h - v + bK < \overline{x}$, the expected welfare is $E\,SW = \int_{\underline{x}}^{\tilde{x}} \mathrm{SW}_{w,3}^* f(x)dx + \int_{\tilde{x}}^{\overline{x}} \mathrm{SW}_{w,2}^* f(x)dx$, where $\tilde{x} = c - h - v + bK$. By the FOC that $\frac{d}{dK} E\,SW = 0$, it can be shown that if $r < \frac{\overline{x}-\underline{x}}{2(1-\delta)}$, the optimal airport capacity is

$$K_w^* = K_{w,3}^* = \frac{1}{b}\left(\overline{x} - c + h + v - \sqrt{2r(1-\delta)(\overline{x}-\underline{x})}\right) \tag{36}$$

Otherwise if $r \geq \frac{\overline{x}-\underline{x}}{2(1-\delta)}$, there is no optimal capacity for the airport in this case.

Comparing welfare levels across the above cases, the optimal capacities can be obtained and are summarized in the following proposition:

Proposition 5: *For a welfare-maximizing airport,*

(i) *if* $r < \frac{\overline{x}-\underline{x}}{2(1-\delta)}$, *the optimal capacity is*

$$K_w^* = K_{w,3}^* = \frac{1}{b}\left(\overline{x} - c + h + v - \sqrt{2r(1-\delta)(\overline{x}-\underline{x})}\right) \tag{37}$$

(ii) *if* $\frac{\overline{x}-\underline{x}}{2(1-\delta)} \leq r \leq \frac{\overline{x}+\underline{x}-2c+2h+2v}{2(1-\delta)}$, *the optimal capacity is*

$$K_w^* = K_{w,2}^* = \frac{1}{b}\left[\frac{\overline{x}+\underline{x}}{2} - c + h + v - (1-\delta)r\right] \tag{38}$$

(iii) *if* $r > \frac{\overline{x}+\underline{x}-2c+2h+2v}{2(1-\delta)}$, *the optimal capacity is 0 or no capacity should be invested.*

Similar to the case of a profit-maximizing airport, the optimal capacity K_w^* of a welfare-maximizing airport increases with δ (i.e. $\frac{\partial K_w^*}{\partial \delta} \geq 0$, where equality is possible at border conditions). The intuition is that the savings in capital cost lead to higher capacity, which accommodates possible high demand in the future. However, optimal capacity K_w^* is not influenced by airport-airline arrangements (i.e. $\frac{\partial K_w^*}{\partial s} = 0$). Similar results can be found for expected welfare, or $\frac{\partial ESW_w^*}{\partial \delta} \geq 0$ and $\frac{\partial ESW_w^*}{\partial s} = 0$. Intuitively, vertical arrangements (represented by parameter s) and airport charge (represented by parameter ω) influence surplus distribution between the airport and its airlines. However, surplus allocation does not change the airport's capacity choice, which is set to maximize expected welfare (total surplus).

Demand uncertainty has similar effects as in the case of profit-maximizing airport. If capital cost is very high relative to travel demand ($r > \frac{\bar{x}+\underline{x}-2c+2h+2v}{2(1-\delta)}$ in our model), the airport will not invest any capacity. Otherwise, if capital cost is very low relative to travel demand (in our model $r < \frac{\bar{x}-\underline{x}}{2(1-\delta)}$), the airport will invest a lot even if the capacity may be partially utilized in the future. If the airport capital cost is moderate (i.e. $\frac{\bar{x}-\underline{x}}{2(1-\delta)} \leq r \leq \frac{\bar{x}+\underline{x}-2c+2h+2v}{2(1-\delta)}$), a welfare-maximizing airport will invest the same amount of capacity as in the case of a deterministic mean demand (i.e. when $x = (\bar{x} + \underline{x})/2$).

To ensure that incentive-compatible agreements can be reached, or win-win cooperation can be arranged between an airport and its airlines without government intervention, the following conditions are to be satisfied, which require that expected welfare and signatory airlines' profits should be larger with the agreement than the case without:

$$\mathrm{E}\, SW_w^*(s,\delta) - \mathrm{E}\, SW_w^*(0,0) \geq 0 \geq 0 \tag{39.1}$$
$$\mathrm{E}\, \pi_{\mathrm{i,w}}^*(s,\delta) - \mathrm{E}\, \pi_{\mathrm{i,w}}^*(0,0) \geq 0, \quad i = 1,2, \tag{39.2}$$

These functions have complex step-wise specifications conditional on capital cost and demand variability. For example, it can be shown that if $r < \frac{\bar{x}-\underline{x}}{2(1-\delta)}$, then

$$\mathrm{E}\, \pi_{i,w}^*(s,\delta) = \int_{\underline{x}}^{\hat{x}^*} \left[\frac{(x-bQ_3^*-c-\omega_{w,3}^*)Q_3^*}{2} + s\left(\left(\omega_{w,3}^* + h\right)Q_3^* - (1-\delta)rK_{w,3}^*\right)\right] f(x)dx +$$
$$\int_{\hat{x}^*}^{\bar{x}} \left[\frac{(x-bQ_2^*-c-\omega_{w,2}^*)Q_2^*}{2} + s\left(\left(\omega_{w,2}^* + h\right)Q_2^* - (1-\delta)rK_{w,3}^*\right)\right] f(x)dx \tag{40.1}$$

where $\hat{x}^* = c - h + 3bK_{w,3}^*$. Otherwise if $r \geq \frac{\bar{x}-\underline{x}}{2(1-\delta)}$, then

$$\mathrm{E}\, \pi_{\mathrm{i},w}^*(s,\delta) = \int_{\underline{x}}^{\bar{x}} \left[\frac{(x-bQ_2^*-c-\omega_{w,2}^*)Q_2^*}{2} + s\left(\left(\omega_{w,2}^* + h\right)Q_2^* - (1-\delta)rK_{w,2}^*\right)\right] f(x)dx \tag{40.2}$$

Closed form solutions cannot be obtained. Our extensive numerical simulations show that there are feasible values of *s* that satisfy these two equations simultaneously. However, no clear relationship among parameters *r*, *s* and δ can be identified, suggesting that the availability of win-win cooperation between airports and airlines depends on various parameters. Some of the simulation results are reported in the Appendix.

5. Summary and Conclusion

To accommodate strong growth in traffic volume in coming years, substantial investments in airport infrastructure are needed. Airlines nowadays play an important role in airport capacity expansion, either through direct/joint investments, or through risk sharing which helps airports raise capital at competitive rates. In return, these airlines are given varying degrees of influence over airport planning, investments, and operations. They also receive financial benefits, either directly in the form of revenue sharing, or indirectly through airport charge discounts or preferential facility use. However, the effects of airport-airline cooperation on airport capacity choices remain unclear. No consensus has been reached with respect to the appropriate policy toward such vertical arrangements.

This study aims to fill this gap in the research by developing a multistage model, in which competing airlines contribute to capacity investments, and share airport revenue proportional to their respective capital commitments. The proposed model simultaneously considers airport-airline vertical arrangements, airline competition, and airport capacity choice in the presence of demand uncertainty. Our analytical results suggest that for a profit-maximizing airport, such a vertical arrangement leads to higher capacity although its profit may not be higher. For a welfare-maximizing airport, such an arrangement has no effect on capacity or social welfare. Capital cost savings brought by airport-airline cooperation, if any, always lead to higher capacity, higher profit for a profit-maximizing airport, and higher welfare in the case of a welfare-maximizing airport. Numerical simulations reveal that win-win outcomes may be achieved for an airport and its airlines (and thus airport-airline vertical arrangements may be sustained) without government intervention.

These results are broadly consistent with previous studies on airport-airline vertical arrangements, which in general conclude that such arrangements may increase welfare and traffic volume by internalizing the positive demand externality between aeronautical services and concession services. Our capacity-enhancing results is also consistent with Sarmento and Brandao (2013) who show that airport-airline profit sharing may display the highest incentive for an airport to invest when compared to alternative vertical relations when the airport maximizes profit. In addition, our findings are consistent with several recent studies on "light-handed" airport regulation,[8] which identified commercial agreements between airlines and airports as a source of efficiency and welfare gains (Forsyth 2004, 2008, Littlechild 2012a, 2012b, Yang and Fu 2014). The empirical investigation by Yang et al. (2014) found that, compared to airports without vertical arrangements with airlines, those with arrangements tend to handle more passengers and aircraft movements, have more gates but lower unit costs, and are more likely to be under public ownership. These empirical findings appear to be

[8] In recent years, formal price regulation has been removed for all major airports in New Zealand and Australia, and for some medium sized airports in the United Kingdom. A "light-handed" regulation regime has been introduced instead, where airport price and service quality are monitored but not directly regulated (Yang and Fu 2014). However, capacity investments have not been formally examined in this emerging literature. Littlechild (2012b) noted that "the Australian light-handed approach is yet to be fully tested with respect to agreements on major investments."

broadly consistent with our analytical results.

We would like to caution readers that the model in this paper considered symmetric airlines only. In practice, dominant carriers often have substantial market power at their hubs, where airline competition might be better modeled as a Stackelberg game instead of a simultaneous game (see Sarmento and Brandao 2013 for an analysis using the Stackelberg formulation without demand uncertainty). With demand uncertainty however, Stackelberg competition needs to assume a specific rule of airline outputs allocation when airport capacity is binding. In the aviation industry, airport slot allocation has been fairly *ad hoc* despite established guiding principles of “grandfather rights”, “use it or lose it” rule, and “new entrant” rule. Future studies on specific airport markets may test the capacity/output allocation schemes being used, and such studies would offer valuable insights into this important issue.

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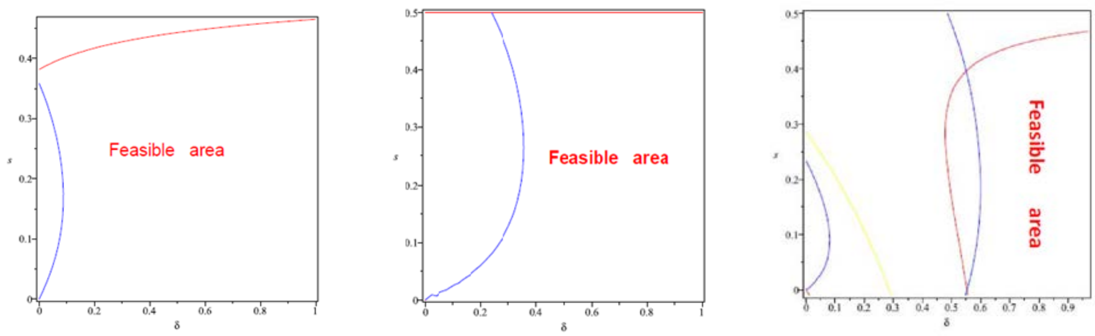
Appendix. Numerical Simulation Results

This section presents the results of some numerical simulations. These numerical simulations are carried out to test if for a particular value of capital saving δ, whether there are feasible values of *s* that can lead to incentive compatible agreements for both the airport and the airlines. For mathematical tractability, simulations presented below are carried out for scenarios when $\underline{x} = 0, \overline{x} = 1$, $b = 1$, $c = 0$ and $h = 0$. Following graphs in Figure A1 depict the feasible areas of investment / revenue sharing proportion *s* in the case of a profit-maximizing airport.

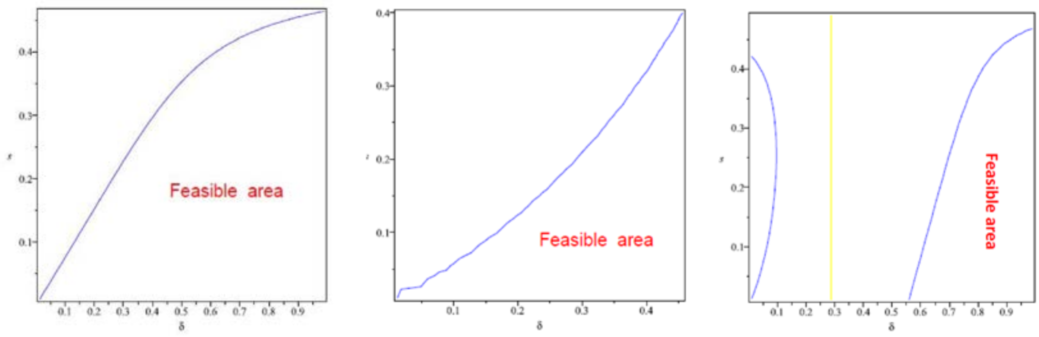


r = 0.3 r = 0.5 r = 0.7

Figure A1. Feasible areas of s at different values of parameters δ and r

in the case of a profit-maximizing airport

Following graphs in Figure A2 depict the feasible areas of parameter *s* in the case of a welfare-maximizing airport. Note since vertical arrangements (as presented by *s*) has no effects on social welfare, the feasible areas are determined mainly by signatory airlines' incentive compatible condition, so long as corresponding airport charges (i.e. ω) satisfy the conditions specified in Proposition 4.



r = 0.3 r = 0.5 r = 0.7

Figure A2. Feasible areas of s at different values of parameters δ and r

in the case of a welfare-maximizing airport