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Rivalry between Airport Ancillary and City-center Supplies

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Abstract

Passengers can buy souvenirs or rent a car at the airport or in the city-center. This paper develops a basic model with unit demands for airport ancillary and city-center demands to derive equilibrium pricing strategies of profit-maximizing airports and city-center companies and evaluates them from the social viewpoint. Passengers are myopic in the sense that only ticket prices matter for flight decisions or foresighted in the sense that non-aeronautical airport and city-center supplies matter for flight decisions, too. We find that the welfare evaluation of equilibrium airport pricing behavior can be independent of whether passengers are myopic or foresighted.

Keywords: Airport privatization; city-center rivalry; ancillary goods; myopic passengers; foresighted passengers

1 Introduction

1.1 Motivation

Public airport ownership is common while private airport ownership and private sector participation in airport businesses become increasingly relevant worldwide. More than 41 percent of global passenger traffic already uses airports with private sector participation (Airport Council International, 2017) and many airport privatization projects are in the implementation phase (Careen, 2019). Airlines express their concerns about this development because they are worried that airport privatization could increase airport charges for airlines and passengers (International Air Transport Association, 2019). The question is whether these concerns are justified and whether governments should abstain from airport privatization or implement regulatory controls to avoid excessive airport charges.

As mentioned by Starkie (2001) and others, the assessment of airport charges in an environment with private and profit-maximizing airports should be based on the consideration of aeronautical and non-aeronautical businesses. Aeronautical businesses include, for example, the supply of runways, boarding bridges, de-icing, security and passenger facilities. Non-aeronautical businesses include the supply of retail concessions, car parking, property and real estate, car rentals, food and beverage, advertising and more. These businesses are a major revenue source for airports. Non-aeronautical businesses, reach almost 40 percent of total airport revenues worldwide (Airports Council International, 2019).

This paper highlights that airports often relate their prices for non-aeronautical goods and services, called *ancillary goods* hereafter, to city-center prices.[1] For instance, Vancouver airport imposes an upper limit on prices for ancillary goods, called *ancillary prices* hereafter, which is determined by city-center prices, whereas Atlanta allows a premium of 10 percent on city-center prices.[2] Hong Kong airport launched an "Urban Price Protection" scheme in 2004.[3] This scheme requires airport retailers and restaurant operators to charge prices that do not exceed the city-center prices. Concessionaires who charge ancillary prices that exceed Hong Kong downtown prices risk termination of their concession contracts. A recent study conducted by the Airport Authority of Hong Kong indeed found that 80 percent of the ancillary items sold at Hong Kong International Airport are priced at or below the corresponding downtown prices. These instances illustrate the rivalry between airports and city-centers, which is the main topic of the present study. They further show that airports employ contractual arrangements intended to directly control ancillary prices of shops located inside the airport area.[4]

[1] See Nicolae et al. (2016) for an analysis of ancillary services in the airline business.

[2] This information is based on personal communication.

[3] Online news article published 7 February 2018 in Chinese with title "AA survey: about 20% of the airport's goods are more expensive than in the city" (Google translate and own translation) at www.hk01.com.

[4] Flores-Fillol (2018) highlight that airports could indirectly control ancillary prices by controlling the number of

1.2 Approach

This paper develops and analyzes a basic airport and city-center model as well as various model extensions in order to derive (i) a better understanding of pricing strategies and equilibrium pricing behavior when privatized airports control both prices for aeronautical services and ancillary prices and compete with city-centers, and (ii) the evaluation of equilibrium pricing behavior from the social viewpoint. In the basic model, individuals have a unit demand for flights and a unit demand for a *good* (passengers may park their one car and not many), where the good can be bought at the airport (again, in this case it is called ancillary good) or in the city-center (in this case it is called the *city-center good*).[5] Ancillary and city-center goods are homogenous in the basic model. The basic model concentrates on a single airport and a single city-center company. The airport chooses a price for aeronautical services, called the *airport charge*, and the ancillary price. Airline markets are atomistic in the basic model and airline costs are normalized to zero so that the airport charge equals the ticket price. The generalized price of traveling is, in the basic model, given by the sum of the ticket price and the travel costs associated with the trip from the city-center to the airport. This captures the notion of myopic passengers in the sense that passengers ignore differences in ancillary and city-center prices when they decide upon traveling. One reason may be that the purchase of flight tickets and actual flight times as well as the corresponding consumption of ancillary or city-center goods can be well separated in time as was pointed out by Zhang and Zhang (2003). The travel costs to the airport from the city-center are high enough to ensure that airports have no interest in prices that encourage individuals to travel to the airport only for shopping reasons. Yet, capturing the theoretical possibility that individuals may travel to the airport only for shopping reasons—shops can be found after but also before security check so that they are also reachable by non-passengers—is still useful in order to derive a detailed understanding of the full set of equilibrium prices, which may involve the pricing of ancillary goods below marginal costs. Finally, the demand for flights is downward sloping in the airport charge (general functional forms are used for flight demand), while the aggregate demand for the good is perfectly elastic in the sense that the consumption of the good yields a constant utility called the good's utility.

1.3 Overview and main results

The analysis starts by identifying demand and profit functions in Section 2. In Section 3, profit functions are used to derive the airport best responses in terms of the airport charge and the ancillary price by iterated deletion of dominated strategies and the city-center best responses in terms of the city-center price. Best responses imply that an equilibrium in pure pricing strategies is missing when

concessionairs and, thus, the level of competition between firms involved in non-aeronautical airport businesses.

[5] The assumption of unit demand for ancillary goods is common for frameworks such as the one developed in the present study. Shilony (1977), Varian (1980) and Ellison (2005) can serve as examples.

the city-center population is finite. An equilibrium in mixed pricing strategies does exist, however, and this equilibrium in mixed strategies can be used to uniquely characterize equilibrium prices by capturing that only a small share of the city-center population will usually be present at the airport. Under these conditions equilibrium airport and city-center prices can be welfare-maximizing because the profit-maximizing airport boosts its demand for ancillary goods by reducing the airport charge, which resembles the results of, for example, Starkie (2001) and Gillen and Mantin (2014) in a context of airport and city-center rivalry.

Section 4 alters the model assumptions in a way that captures the notion of foresighted passengers. Experienced passengers such as, for example, business passengers are likely to anticipate the true generalized price of traveling taking into account, for example, the difference between airport and city-center car rental prices (for example, Czerny, 2013). Czerny, Shi and Zhang (2016) empirically estimated that a one-dollar increase in the daily car rental price reduces passenger demand at US airports by more than 0.36 percent, which supports the idea that passengers are indeed foresighted. Bracaglia, D'Alfonso and Nastasi (2014) pointed out that the increased use of online offerings of ancillary airport services such as car parking, car rental and shopping can increase the passenger awareness of ancillary prices for all passengers, that is, business *and* leisure passengers. The analysis reveals the following *independence result*: If equilibrium airport and city-center prices are welfare maximizing in the case of myopic passengers they are also welfare-maximizing in the case of foresighted passengers. The intuition for the welfare optimality of equilibrium airport prices differ, however. With myopic passengers, the equilibrium airport charge depends on the ancillary businesses, while the welfare-maximizing airport charge depends on the marginal cost of traveling (which are normalized to zero in the present study) and is independent of ancillary businesses. This ensures that ancillary businesses can, depending on the importance of ancillary businesses measured by the good's utility, imply equilibrium airport charges that are also optimal from the welfare viewpoint. With foresighted passengers, however, it is the welfare-maximizing generalized price that depends on the ancillary supply, which ensures that equilibrium and welfare-maximizing prices can be equal. This is because, in this case, flight decisions depend on the difference between (i) the sum of the airport charge and the ancillary price and (ii) the good's utility. This finding shows that policy makers may not need to worry about the foresightedness of passengers in their assessment of privatization policies.

Section 5 extends the basic model by deviating from unit demands, capturing price regulation and preferences for ancillary goods relative to city-center goods as well as airline market power. These extensions are separately addressed in four subsections. The first subsection considers downward sloping demands for the good to capture that the individual demand for the good can be a function of the good's price. This may be the case for, for example, food and beverages, retail goods, and even car parking (passengers may be willing to park their car for a longer period of time when car parking prices are reduced). In this subsection we show that the independence result is robust with respect to equilibrium airport charges, that is, the welfare evaluation of equilibrium airport charges is independent of whether passengers are myopic or foresighted. However, downward sloping individual demands still matter because equilibrium city-center prices are excessive in the scenario with downward sloping individual demands for the good, while a welfare-optimal zero ancillary price is used in equilibrium to boost passenger demand when passengers are foresighted. The second subsection shows that profits from non-aeronautical businesses become more important for a profit-maximizing airport when airport charges are regulated relative to a scenario where airport charges are unregulated. The third subsection captures that passengers may prefer ancillary over city-supply as can be, for example, the case for car parking and car rentals, and shows how such preference structures can soften the competition between airport and city-center companies in the sense that the equilibrium ancillary price can exceed the equilibrium city-center price. The fourth subsection shows that the results in the preceding parts are largely independent of the presence of airline market power.

1.4 Literature review and contribution

Previous studies have addressed the pricing of airport infrastructure and ancillary supplies.[6] Most of them abstracted away from the rivalry between airports and city centers, and many concentrated on myopic passengers, which means they also abstracted away from the possibility that prices for, for example, airport car parks can affect passenger demand (for example, Zhang and Zhang, 1997, 2003 and 2010). These studies showed that, in a context with airport congestion, profit-maximizing airport charges will be reduced by ancillary businesses in order to boost passenger demand but that they are still excessive from the social viewpoint. The discrepancy between profit- and socially optimal airport charges occurs because the profit-maximizing airport ignores the consumer surplus arising from ancillary supply. Czerny (2006) concentrated on foresighted passengers and showed that ancillary supply can increase the profit-maximizing airport charge relative to a situation where ancillary supplies are absent. The intuition is that ancillary supplies together with low and even loss-making prices for ancillary supplies can make traveling more convenient and, thus, boost passenger demand leading to an increase in the profit-maximizing airport charge and profit from aeronautical services. Gomes and Tirole (2018), by considering industries different from the airport industry, go so far to propose policies that would ban loss-making on the ancillary goods. Czerny (2009 and 2013) developed a scenario where foresighted passengers can choose between airport and city-center supplies and showed that, for exogenous ancillary and city-center prices (these prices are endogenous in the present study), profit-maximizing airport charges can be welfare-maximizing. D'Alfonso, Jiang and Wan (2013) captured the role of city-center consumption for the evaluation of profit-maximizing airport prices, too, and explored the relationship between ancillary businesses and congestion when passengers are myopic.

[6] See Zhang and Czerny (2012) and D'Alfonso and Bracaglia (2017) for survey articles that discuss the recent literature on the pricing of aeronautical and non-aeronautical airport supplies.

Flores-Fillol, Iozzi and Valletti (2018) analyze both myopic and foresighted passengers in a unifying framework (city-center considerations are absent in their study). They show that a small degree of foresightedness can lead to a significant change in airport pricing behavior. D'Alfonso, Bracaglia and Wan (2017) adopt the unifying framework developed by Flores-Fillol, Iozzi and Valetti in order to analyze "airport cities" where ancillary supply is consumed by passengers but also by non-travelers. Kidokoro, Lin and Zhang (2016) and Kidokoro and Zhang (2018), analyzed capacity choices and the self-financing property when airports invest in both the capacity for aeronautical and non-aeronautical businesses when ancillary prices are given. The present study contributes to this strand of the literature by analyzing the endogenous pricing of airport and city-center supplies in the cases of myopic and foresighted passengers and by showing that the social evaluation of airport profit-maximizing behavior can be independent of whether passengers are myopic or foresighted.

2 The Basic Model

There is a profit-maximizing monopoly airport that serves a passenger quantity denoted by q. The airport charges a price denoted by r per passenger to airlines. Airline markets are considered as atomistic, and all other airlines' costs are normalized to zero, which helps us to concentrate on airports because r determines the ticket price, called airport charge hereafter, under these conditions. The airport further offers ancillary goods and services for a price, called ancillary price hereafter, denoted by p_a (subscript "a" stands for airport).[7] In the area of ancillary businesses the airport is a rival of a company that offers the same goods in the city center for a price denoted by p_c (subscript "c" stands for city center), called city-center price hereafter.[8] Thus, individuals can choose to buy at the airport or in the city center. However, traveling from the city center to the airport incurs travel costs T. These travel costs include all the travel costs that are exogenous to the airport, thus, cannot be influenced by the airport. These costs, therefore, do include, for example, fuel costs for driving the own or a rented car or the costs of using public transport, but they do not include, for example, car parking and car rental prices, which are controlled by the airport. The city population is given by Q and every individual consumes at most one unit of the "good," where the good could be the ancillary good or the city-center good. In the present basic model, passengers are myopic in the sense that their traveling decisions depend on the ticket prices, thus, airport charges, but are independent of the goods' prices p_a and p_c. This rules out that passengers may fly more often because they can buy goods

[7] The airport may offer take-it-or-leave-it contracts to concessionaires where they control the ancillary prices and fully internalize the profits of concessionaires throught fixed payments. This contract structure is motivated by the observation that airports do impose upper limits on ancillary prices at airports in, for example, Atlanta and Vancouver.

[8] Some sellers of ancillary goods may also be sellers in the city center. Our analysis is robust with respect to such constellations for the following reasons. Since the airport uses take-it-or-leave-it contracts to control ancillary prices and fully internalize the sellers' profits, sellers would be better off by selling at their shops in the city center. This scenario is well represented by the rivalry case established in the present study.

at the airport at a lower price than in the city center.

To economize notation and write the passenger demand only as a function of the airport charge r and omit travel costs T, the passengers' total benefit from traveling is, without loss of generality, denoted by $\overline{B}(q)$ with $\overline{B}(q) = B(q) + qT$, where $B(q)$ is strictly concave in q. Denote the generalized price of traveling by η, which can be written as $\eta = r + T$. Passenger demand depending on the ticket price, denoted by $D(r)$, is determined by the equilibrium condition $\overline{B}' = \eta$, which leads to $\overline{B}' - T = B' = r$, and $D' = 1/B'' < 0$. Thus, the concavity of B implies that the passenger demand is decreasing in the airport charge r.

Example 1 *Consider the quadratic benefit function* $\overline{B}(q) = \overline{a}q - bq^2/2$. *Equilibrium demand is determined by* $\overline{a} - bq = r + T$. *Consider* $\overline{a} = a + T$, *which implies* $B(q) = (a + T)q - bq^2/2$ *and leads to demand* $D(r) = (a - r)/b = (\overline{a} - T - r)/b$, *which illustrates the economization of notation.*

Consumers can consume the good at the airport or in the city-center both of which yields utility denoted by u. To ensure that, in equilibrium, only travelers will buy the good at the airport, it is assumed that travel costs T are high enough in the sense that $T > u$. Consider the demand for goods inside the airport area, denoted by $d_a(p_a, p_c)$. Here it is useful to distinguish three cases.

The first case is characterized by $p_a > p_c \cup p_a > u$. In this case consumers will not buy ancillary goods, that is, $d_a = 0$. If $p_a > p_c$, this is because the city-center price is low relative to the ancillary price, which means that everyone (including passengers) is better off by buying the goods in the city center. If $p_a > u$, this is because the ancillary price exceeds the consumption utility.

The second case is characterized by $((p_c > u) \cap (u \geq p_a > u - T)) \cup ((u \geq p_c \geq p_a) \cap (u \geq p_a \geq p_c - T))$. In this case, only travelers buy ancillary goods, that is, $d_a = D$. If $((p_c > u) \cap (u \geq p_a > u - T))$, the city-center price exceeds consumption utility; thus, no one buys the city-center good. Rearranging $p_a > u - T$ leads to $p_a + T > u$, which shows that also no one will visit the airport only for shopping reasons because the sum of the ancillary price and travel cost is too high relative to the consumption utility. But travelers, who pay the traveling cost T anyway, consume ancillary goods because the ancillary price is sufficiently low relative to the consumption utility. If $((u \geq p_c \geq p_a) \cap (u \geq p_a \geq p_c - T))$, the ancillary price plus the traveling cost, $p_a + T$, is higher than the city-center price; thus, non-travelers will not visit the airport only for shopping reasons. But, for travelers it holds that $(p_c \geq p_a) \cap (u \geq p_a)$, which means that they can achieve a higher consumer surplus by ancillary consumption rather than city-center consumption.

The third case is characterized by $((p_c > u) \cap (u - T \geq p_a)) \cup (u \geq p_c > p_a + T)$. In this case everyone will go to the airport to buy ancillary goods independent of traveling activities, that is, $d_a = Q$. If $((p_c > u) \cap (u - T \geq p_a))$, p_c exceeds the utility of the ancillary goods so no one will buy city-center goods. But $u \geq p_a + T$, which means that the ancillary price is sufficiently low to justify visiting the airport even for non-travelers. If $u \geq p_c > p_a + T$, the sum of the ancillary price and traveling cost is still lower than the city-center price; thus, travelers and non-travelers buy ancillary goods. Note that $p_a + T \leq \min\{u, p_c\}$ implies that p_a is strictly negative by the assumption that $T > u$. This means that the airport loses money in the area of ancillary businesses whenever they chose an ancillary price low enough to convince non-travelers to visit the airport only for shopping reasons. Altogether, the demand for ancillary goods can be written as

$$d_a(r, p_a, p_c) = \begin{cases} 0 & \text{for} \quad p_a > p_c \cup p_a > u \\ D & \text{for} \quad ((p_c > u) \cap (u \geq p_a > u - T)) \cup ((u \geq p_c \geq p_a) \cap (u \geq p_a \geq p_c - T)) \\ Q & \text{for} \quad ((p_c > u) \cap (u - T \geq p_a)) \cup (u \geq p_c > p_a + T). \end{cases} \tag{1}$$

The demand for city-center goods, denoted by d_c, can be derived by distinguishing three cases as well. The first case can be characterized by $(p_c > u) \cup (u \geq p_c > p_a + T)$. If $p_c > u$, the city-center price exceeds the consumption utility, which leads to zero demand for city-center goods, that is, $d_c = 0$. If $u \geq p_c > p_a + T$, the price difference, $p_c - p_a$, is larger than travel costs T. In this case, even non-travelers visit the airport for shopping reasons because the ancillary price is low enough to justify the extra travel costs, which leads to zero city-center demand. The second case is characterized by $(u \geq p_c \geq p_a) \cap (u \geq p_a \geq p_c - T)$, the airport's ancillary price plus traveling cost, $p_a + T$, is higher than the city-center price, so only travelers will buy ancillary goods. The third case is characterized by $(u \geq p_c) \cap (p_a > p_c)$, the city-center price is lower than the consumption utility, while the ancillary price is higher than the city-center price; thus, travelers and non-travelers will buy city-center goods.

Altogether, the city-center demand can be written as

$$d_c(r, p_a, p_c) = \begin{cases} 0 & \text{for} \quad (p_c > u) \cup (u \geq p_c > p_a + T) \\ Q - d_a & \text{for} \quad (u \geq p_c \geq p_a) \cap (u \geq p_a \geq p_c - T) \\ Q & \text{for} \quad (u \geq p_c) \cap (p_a > p_c) \end{cases} \tag{2}$$

The airport derives revenues from two sources. The first source is the infrastructure supply, which leads to revenue rD. The second source is the supply of ancillary goods, which leads to revenue $p_a d_a$. To concentrate on the demand side, we normalize the costs of airport supply to zero. The airport profit, denoted by $\Pi_a(r, p_a, p_c)$, can be written as

$$\Pi_a(r, p_a, p_c) = rD(r) + p_a d_a(r, p_a, p_c). \tag{3}$$

The supply of city-center goods leads to revenues $p_c d_c$. The city-center's costs are normalized to zero as well. Letting $\Pi_c(r, p_a, p_c)$ denote the city-center profit it holds that

$$\Pi_c(r, p_a, p_c) = p_c d_c(r, p_a, p_c). \tag{4}$$

We consider a one-shot game where the airport chooses profit-maximizing prices for infrastructure services and ancillary goods and simultaneously the city-center chooses its profit-maximizing price.

3 Welfare Evaluation of Equilibrium Prices

To identify equilibrium pricing strategies, it is useful to first derive the airport's and the city-center's best responses in terms of their prices. For the airport, this first step will be divided in two further steps. These two steps help to gradually increase complexity by first assuming that the airport can change only the airport charge or only the ancillary price before the simultaneous choice of these two airport prices is considered in a next step. Airport and city-center best responses are then used to derive and analyze equilibrium pricing behaviors.

3.1 Best responses

Airport charge. This part derives the airport's best responses in terms of airport charge, r, for given ancillary and city-center prices p_a and p_c, respectively. These best responses, denoted by r^{br}, are given by $r^{br} = \arg\max_r \Pi_a(r, p_a, p_c)$. It is useful to distinguish three cases.

The first case is characterized by $p_a > \min\{u, p_c\}$. In this case, the revenue from ancillary businesses is zero and the airport profit can be written as $\Pi_a = rD$. The profit-maximizing price is determined by the first-order condition $\partial\Pi_a/\partial r = 0$; this leads to the monopoly price $r^{br} = -D/D'$.[9] The right-hand side is the absolute value of the inverse semi-price elasticity of passenger demand. In this case, the revenue from ancillary businesses is zero as p_a exceeds the good's utility u.

The second case is characterized by $p_a < \min\{u, p_c\} - T$ and implies airport profit $\Pi_a = rD + p_a Q$. This leads to $r^{br} = -D/D'$. The main feature of the present case is that travelers and non-travelers will visit the airport to consume the good, which leads to airport revenues from ancillary goods supply equal to $p_a Q$; but, because $T > u$, p_a and the revenues from ancillary supply are negative. As will be shown below, this scenario cannot be part of a set of best responses where the airport controls both the airport charge and the ancillary price because the extra demand from non-travelers reduces airport profit at such a low ancillary price.

The third case is characterized by $(p_a \leq \min\{u, p_c\}) \cap (\min\{u, p_c\} - T \leq p_a \leq \min\{u, p_c\})$ and implies airport profit $\Pi_a = (r + p_a) D$. Using the first-order condition, $\partial\Pi_a/\partial r = 0$, the profit-maximizing airport charge can be written as $r^{br} = -D/D' - p_a$. Rearranging yields $r^{br} + p_a = -D/D'$, where the left-hand side shows the sum of the airport charge and ancillary price, while the right-hand side is the absolute value of the inverse semi-price elasticity, again. In this case it is useful to solve for the sum of prices, $r + p_a$, because all passengers fly *and* consume the ancillary good, thus, the sum of the prices, $r + p_a$, is the relevant factor for the airport. The airport charge is low relative to the previous case. This is because passengers do not buy in the city center because p_c is higher than the utility u, while they consume the ancillary good. So, the airport decreases the airport charge by p_a to

[9] To ensure the existence of the profit-maximizing price, passenger demand D is assumed to be log-concave in the airport charge.

attract more passengers and boost ancillary demand. Anyway, individuals abstain from visiting the airport just for shopping reasons because $p_a + T$ is larger than $\min\{u, p_c\}$.

Altogether, in the case of myopic passengers, the airport's best response in terms of the airport charge can be summarized as

$$r^{br}(p_a, p_c) = \begin{cases} -D/D' & \text{for} \quad (p_a > \min\{u, p_c\}) \cup (p_a < \min\{u, p_c\} - T) \\ -D/D' - p_a & \text{for} \quad \min\{u, p_c\} - T \leq p_a \leq \min\{u, p_c\} \end{cases} \tag{5}$$

where D and D' on the right-hand side are both evaluated at $r = r^{br}$ (in equation (5) and hereafter arguments are omitted to economize notation).

Ancillary price. The airport best responses in terms of the ancillary price, p_a, for a given airport charge such that $D > 0$ (to concentrate on the interesting cases with positive passenger demand), and non-negative city-center price, $p_c \geq 0$ (to concentrate on non-negative city-center profit) can be defined as $p_a^{br} = \arg\max_{p_a} \Pi_a(r, p_a, p_c)$. It is useful to distinguish two cases.

The first case is characterized by $p_c > u$. In this case the city-center demand is zero, while airport profit can be written as $\Pi_a = (r + p_a) D$. This airport profit is strictly increasing in the ancillary price as long as p_a is less than utility u, which leads to the best response $p_a = u$. In this scenario, all passengers consume ancillary goods at the airport and pay a price equal to the good's utility.

The second case is characterized by $p_c \leq u$. In this case, airport profit can be written as $\Pi_a = rD + p_a d_a$, where rD is fixed because r is considered as given. Airport profit is strictly increasing in the ancillary price as long as p_a is less than utility p_c, which leads to the best response $p_a = p_c$. All passengers consume ancillary goods and pay the maximum amount they are wiling to pay for the ancillary good given the city-center price.

Altogether, in the case of myopic passengers, airport's best responses in terms of the ancillary price p_a can be summarized as

$$p_a^{br}(p_c) = \begin{cases} u & \text{for} \quad p_c > u \\ p_c & \text{for} \quad p_c \leq u \end{cases} \tag{6}$$

(for $p_c \geq 0$).

Airport charge and ancillary price. Consider the simultaneous choice of infrastructure and ancillary prices. These best responses are given by

$$(r(p_c), p_a(p_c))^{br} = \arg\max_{r, p_a} \Pi_a. \tag{7}$$

Best responses in (5) and (6) can be used to derive the best responses (7) by iterative deletion of dominated strategies. For instance, best responses in (6) imply that the ancillary price will never (strictly) exceed the minimum of the ancillary utility and city-center price, $\min\{u, p_c\}$, and the airport will charge a positive ancillary price, that is, an ancillary price that encourages non-travelers to visit the airport only for shopping reasons can be ruled out. Altogether, the best responses in terms of the airport charge and ancillary price are unique and can be written as

$$(r(p_c), p_a(p_c))^{br} = \left(-D/D' - \min\{u, p_c\}, \min\{u, p_c\}\right) \tag{8}$$

for myopic passengers and a given non-negative city-center price, $p_c \geq 0$. The best responses in (8) depend on the semi-price elasticity of passenger demand, the good's utility and the city-center price.

City-center price. This part is concerned with the best price response of the city-center company, which can be defined as $p_c^{br} = \arg\max_{p_c} \Pi_c(r, p_a, p_c)$. It is useful to denote a critical price denoted by $\tilde{p}$ with

$$\tilde{p} = u\frac{(Q-D)}{Q}, \tag{9}$$

where the right-hand side is non-negative. This critical price describes the ancillary price where the city-center company is just indifferent between serving non-travelers or travelers and non-travelers. It is useful to distinguish four cases.

The first case is characterized by $p_a < u - T$, which means that the ancillary price is negative and so low that also non-travelers would visit the airport for shopping reasons. In this case, the city-center company charges any non-negative price and generates zero revenue.

The second case is characterized by $u - T \leq p_a \leq \tilde{p}$. In this case, the city-center company will not charge a price that strictly exceeds the ancillary utility u because this would imply a profit of zero, while a city-center price equal to the good's utility, u, leads to a strictly positive profit $\Pi_c = u(Q-D)$. The city-center company could decide to undercut the airport by charging a city-center price $p_a - \varepsilon$, which would lead to profit $\Pi_c = (p_a - \varepsilon)\,Q$ for $\varepsilon \to 0$. But, because the ancillary price is smaller than the critical price $\tilde{p}$, undercutting is not a best response.

The third case is characterized by $\tilde{p} < p_a \leq u$. In this case, undercutting is a best response because the ancillary price is high enough to ensure that serving the entire city population, including passengers, at a lower price yields a profit that is at least as high as the profit that could be achieved by charging a price equal to u to non-travelers.

The fourth case is characterized by $p_a > u$, which means that the demand for ancillary goods is zero because the price exceeds u. In this case, the city-center profit, p_cQ, is increasing in the city-center price as long as this price does not exceed u, which implies that the city-center company charges a price equal to u.

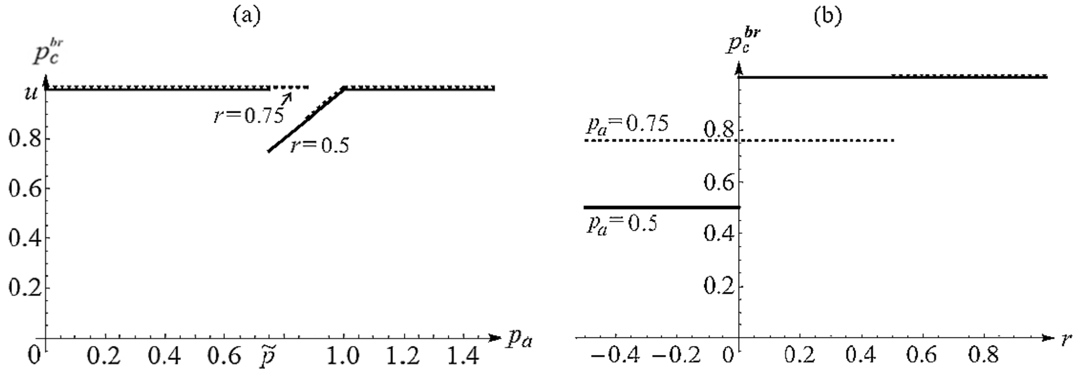

Figure 1: Best responses in terms of p_c for a given airport charge r, part (a), or for a given ancillary price p_a, part (b)

Altogether, in the case of myopic passengers, the city-center best responses can be written as[10]

$$p_c^{br}(r,p_a) = \begin{cases} p_c \geq 0 & \text{for} \quad p_a < u - T \\ u & \text{for} \quad (p_a > u) \cup (u - T \leq p_a \leq \tilde{p}) \\ p_a - \varepsilon & \text{for} \quad \tilde{p} < p_a \leq u. \end{cases} \tag{10}$$

The following example illustrates city-center best responses depending on ancillary prices p_a and airport charges r.

Example 2 *Consider the quadratic passenger utility $B = aq - q^2/2$, which leads to linear passenger demand, $D = a - r$, and parameter instances $a = u = 1$ and $T = Q = 2$ (the following examples will be based on these functional and parameter specifications). Figure 1 displays the city-center best responses depending on p_a in part (a) for given airport charges $r = 3/4$ (dashed line) and $r = 1/2$ (solid lines) and depending on the airport charge r in part (b) for given ancillary prices $p_a = 3/4$ (dashed lines) and $p_a = 1/2$ (solid lines).*

Consider part (a). The airport charge $r = 1/2$ (solid lines), leads to the critical price $\tilde{p} = 3/4$. Thus, for $p_a \leq 3/4$, undercutting is not a sensible strategy because the ancillary price is too low, which leads to best responses $p_c = 1$. Undercutting is a sensible strategy for ancillary prices satisfying $u > p_a > 3/4$, which leads to best responses $p_a - \varepsilon$ for $u > p_a > 3/4$. For $p_a > u$, undercutting is not a sensible strategy again because city-center demand will be zero; thus, in this situation, the city-center best response is to charge a price that is equal to the ancillary utility of 1. The airport charge $r = 3/4$ (dashed lines), leads to the critical price $\tilde{p} = 7/8$. The other illustrations remain the same as in $r = 1/2$.

Consider part (b). The ancillary price $p_a = 1/2$ (solid lines), leads to the critical price $\tilde{p} = (1 + r)/2$. For $r = 0$, $p_a = \tilde{p} = 1/2$. Thus, undercutting is a sensible strategy for $r < 0$, which implies

[10]Best responses for the case $\tilde{p} < p_a \leq u$ are written as $p_c^{br}(r,p_a) = p_a - \varepsilon$. Here and hereafter, this is or will be, respectively, a slight abuse of notation, which is not affecting our results, because ε is essentially undefined.

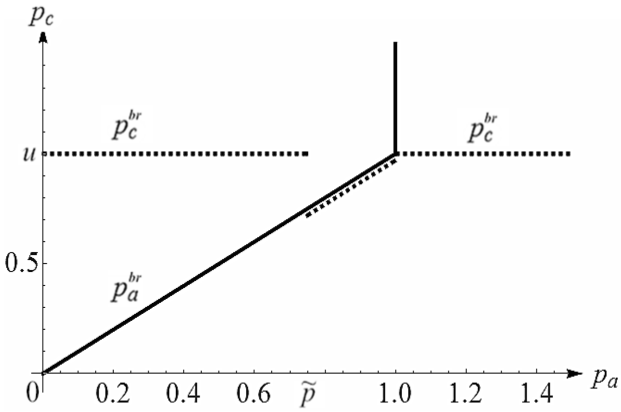

Figure 2: Best responses in terms of the ancillar price and the city-center price for a given airport charge

$p_c^{br} = p_a - \varepsilon$, *because passenger numbers and the gain from undercutting are increased with* $r < 0$ *relative to* $r = 0$. *For* $r \geq 0$, *undercutting is not a sensible strategy because passenger numbers and the gains from undercutting are reduced relative to* $r = 0$, *which implies* $p_c^{br} = u = 1$. *The ancillary price* $p_a = 3/4$ *(dashed lines), also leads to the critical price* $\tilde{p} = (1 + r)/2$, *and in this parameter instance,* $p_a = \tilde{p} = 3/4$ *for* $r = 1/2$. *In this sense, undercutting becomes more attractive for higher values of the ancillary price because undercutting is a best response also for positive values less than* $1/2$, *while negative airport charges are required for* $p_a = 1/2$.

3.2 Equilibrium pricing strategies

The airport and city-center best responses in (8) and (10), respectively, show that neither the ancillary nor the city-center price exceeds the ancillary utility u. Furthermore, the city-center company undercuts the ancillary price as long as it exceeds the critical price $\widetilde{p}$. This is because in this case the ancillary price is high enough to justify a city-center price lower than u, which ensures that the city-center also serves passengers. The airport will respond to undercutting by equalizing the (non-negative) city-center price in order to ensure that passengers remain to be served by the airport. The city-center company will undercut the ancillary price only until the ancillary price reaches the critical price $\widetilde{p}$. If this is the case, the city-center will jump back to charging a price equal to u, which also induces the airport to raise its ancillary price and so forth. Since a Nash equilibrium in pure pricing strategies, indicated by superscript N, exists only if there are price constellations that satisfy the two conditions $\left(r(p_c^N), p_a(p_c^N)\right)^{br} = \left(r^N, p_a^N\right)$ and $p_c^{br}(r^{br}(p_c^N), p_a^{br}(p_c^N)) = p_c^N$, that is, best responses must be mutually consistent, it holds that:

Proposition 1 *If passengers are myopic and the city-center population is finite,* $Q < \infty$, *a Nash equilibrium in pure pricing strategies does not exist.*

The following example illustrates:

Example 3 *Figure 2 displays the best responses in terms of the ancillary price and the city-center price for a given airport charge, $r = 1/2$. The best responses do not intersect. For ancillary prices less than $\widetilde{p}$, the city center best response is to set the price equal to u, which implies the ancillary price response of u. But, if the ancillary price is equal to u, it is larger than the critical price $\widetilde{p}$, which means that the city-center company will now undercut the ancillary price. This leads to mutual undercutting until the ancillary price reaches the critical price $\widetilde{p}$. However, for an ancillary price equal to $\widetilde{p}$, the city-center best response jumps to u again and so forth. Thus, there is no equilibrium in pure pricing strategies in this example.*

Let $F_a(p_c)$ denote the cumulative density function of a mixed pricing strategy for the ancillary price and $F_c(p_a)$ denote the corresponding mixed pricing strategy for the city-center price. It holds (the proof is relegated to Appendix A):

Proposition 2 *If passengers are myopic and the city-center population is finite, $Q < \infty$, a Nash equilibrium in mixed pricing strategies exists, where the airport's atomless mixed pricing strategy can be written as*

$$F_a(p_c) = \begin{cases} 0 & \text{for} \quad p_c \leq \widetilde{p} \\ \frac{p_c Q - u(Q-D)}{p_c D} & \text{for} \quad \widetilde{p} \leq p_c \leq u \\ 1 & \text{for} \quad p_c \geq u. \end{cases} \tag{11}$$

and the city-center's mixed pricing strategy, which contains an atom at $p_c = u$, can be written as

$$F_c(p_a) = \begin{cases} 0 & \text{for} \quad p_a \leq \widetilde{p} \\ 1 - u\frac{Q-D}{p_a Q} & \text{for} \quad \widetilde{p} \leq p_a < u \\ 1 & \text{for} \quad p_a = u. \end{cases} \tag{12}$$

Figure 3 uses numerical instances $u = 1$ and $D = 1/4$ to illustrate airport's and the city-center company's equilibrium mixed pricing strategies for populations $Q = 1$ (dashed lines) and $Q = 3$ (solid lines). The airport's mixed pricing strategy is represented by the upper function, while the city-center's mixed strategy is represented by the lower function. This illustrates that the airport has a higher probability of undercutting than the city-center. The figure further illustrates that equilibrium prices approach utility u when the city-center population increases.[11]

To capture that only a small fraction of the city population visits the airport at a specific point in time, the following assumption is applied here (and hereafter):[12]

Assumption 1 *The city population is large in the sense that $Q \to \infty$.*

[11] See Hirata (2009) for a discussion of asymmetric mixed pricing strategies in a Bertrand-Edgeworth oligopoly.

[12] Take Hong Kong in the year 2016 as an example. At that time, the population was 7.3 Mio., the number of visitors per year was 57 Mio., and these visitors stayed in Hong Kong for around 3.3 days in average. Thus, the total number of people in Hong Kong per day is 7.8 Mio. The yearly number of passengers in Hong Kong was around 70 Mio. in 2016 of

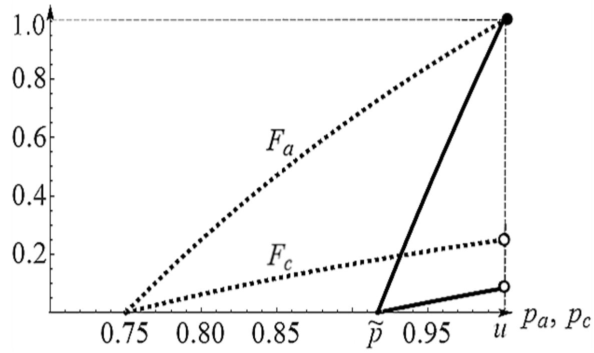

Figure 3: Mixed pricing strategies for $u = 1$ and $D = 1/4$, and populations $Q = 1$ (dashed lines) and $Q = 3$ (solid lines)

This assumption ensures that the critical price, $\widetilde{p}$, approaches the utility u. With a slight abuse of notation, we write that $\widetilde{p} = u$ given 1. Furthermore, the first lines on the right-hand sides of equations (11) and (12) imply that the probabilities of charging ancillary and city-center prices lower than the utility u are both zero when $\widetilde{p} = u$. This means that the equilibrium pricing strategies can be described as:

Proposition 3 *For myopic passengers and given Assumption 1,* $p_a^N = p_c^N = u$ *and* $r^N = -D/D' - u$.

This shows that the equilibrium airport charge is reduced by an amount that is equal to the good's utility relative to a situation where ancillary businesses are absent. Thus, the equilibrium airport charge is reduced to boost non-aeronautical businesses when passengers are myopic.

3.3 Welfare evaluation

We wonder how the equilibrium airport and city-center prices should be evaluated from the social viewpoint. Assuming that policy makers put the same weight on the well-being of producers and consumers, policy makers may be interested in maximizing the sum of producer and consumer surplus, typically called welfare. Letting $W(q, q_a, q_c)$ denote the welfare generated by airport and city-center markets, in which q_a denotes the consumption of ancillary goods and q_c denotes the consumption of city-center goods, it holds that

$$W(q, q_a, q_c) = B(q) + (q_a + q_c)\, u \tag{13}$$

given that only travelers consume airport ancillary goods. In this scenario, welfare maximization requires that $B' = 0$ and $q_a + q_c = Q$.[13] The welfare-maximizing outcome can be achieved for ticket

which around 30 percent were transfer or transit passengers. Considering that average individuals sleep around 8 hours and spend two hours at the airport, the share of passengers in the airport relative to the number of people in Hong Kong reaches 0.2 percent (that is, 99.8 percent of the people in Hong Kong are outside the airport area at a given moment in time).

[13] The strict concavity of the benefit function, $B(q)$, ensures the existence of a welfare maximum.

prices $r = 0$, $p_c \leq u$, and $p_a > p_c - T$ because this pricing system ensures that everyone who has a benefit from flying that is at least as high as the travel cost to the airport, T, flies, that everyone consumes the airport ancillary or city-center goods, and that no individual travels to the airport only for shopping reasons, which would lead to excessive traveling costs. The equilibrium prices described in Proposition 3, imply the following:

Proposition 4 *For myopic passengers and given Assumption 1, airport and city-center prices maximize welfare if $u = -D/D'$ in equilibrium, while passenger quantities are excessive or too low from the social viewpoint if $u > -D/D'$ or $u < -D/D'$ in equilibrium, respectively.*

To derive an intuition, it is useful to understand that airport ancillary supply can be welfare-neutral (Czerny, 2009).[14] Ancillary supply is considered as welfare-neutral if the consumption of the good is independent of ancillary supply. In the present scenario with myopic passengers, this is the case in the sense that passengers and non-travelers are indifferent between ancillary and city-center consumption and thus the aggregate consumption of the good is independent of the passenger quantity. More specifically, $d_a(p_a^N, p_c^N) + d_c(p_a^N, p_c^N) = Q$, where the right-hand side is independent of passenger demand D. Welfare-neutrality implies that if individuals do not fly and, thus, do not consume the ancillary good, the corresponding surplus will still be generated by the consumption of the city-center good. As pointed out by Czerny (2009), welfare neutrality can be used to explain why profit-maximizing airport prices can be welfare-maximizing. With welfare neutrality, the welfare-maximizing airport charge is independent of the ancillary supply because the surplus generated by the ancillary consumption of passengers will also be generated if individuals do not fly and, thus, consume the city-center good at equilibrium prices. On the other hand, the profit-maximizing airport charges are heavily dependent on the ancillary supply. Altogether, it is therefore possible that airport profit-maximizing pricing behavior is welfare-maximizing.

By contrast, Zhang and Zhang (2003) found that profit-maximizing airport charges are excessive from the social perspective given that ancillary supply contributes to welfare and, thus, is not welfare-neutral in the above mentioned sense. In their scenario, airport ancillary goods consumption may generate some consumer surplus that cannot be internalized by the airport, which leads to excessive airport charges from the social viewpoint. Zhang and Zhang (2010) and Kidokoro, Lin and Zhang (2016) developed scenarios where the welfare-maximizing airport charge is reduced by a negative term that is used to increase passenger numbers and boost non-aeronautical airport businesses. Such a negative term is missing in the present scenario with myopic passengers, which implies welfare-maximizing airport charge $r = 0$, because the non-aeronautical supply can be characterized as welfare-neutral.

[14] A revised version of Czerny (2009) has been published as Czerny (2013). For an extensive discussion of the corresponding literature see Zhang and Czerny (2012) and D'Alfonso and Bracaglia (2017).

4 Foresighted Passengers

Customers can be myopic or foresighted (for example, Shulman and Geng, 2013). While the previous section concentrated on myopic passengers, this part concentrates on foresighted passengers, whose traveling decisions depend on airport charges, ancillary prices and city-center prices.

To capture the notion of foresighted passengers, the generalized price of traveling, η, is rewritten as $\eta = \eta(r, p_a, p_c)$. To identify how the generalized price depends on airport and city-center prices, it is useful to distinguish three cases. The first case is characterized by $p_a > u$, which implies that nobody will buy ancillary goods at the airport and the generalized price is simply given by the sum of the ticket price and the travel cost, $r + T$. The second case is characterized by $p_a \leq u, p_c > u$, which implies that city-center consumption is zero and that the generalized price of traveling is determined by the ticket price r, travel cost T, and the difference between p_a and u, $p_a - u$, where this difference lowers the generalized price. This captures that individuals can be encouraged to travel if traveling is associated with an extra benefit from the consumption of the ancillary good. The third case is characterized by $p_a \leq p_c \leq u$, which implies that the generalized price of traveling is determined by the ticket price r, travel cost T and the difference between p_a and p_c, $p_a - p_c$. This captures that individuals can be encouraged to travel if traveling is associated with an extra benefit that, in this case, arises because ancillary good consumption is cheap relative to city-center consumption. This can be summarized as

$$\eta(r, p_a, p_c) = \begin{cases} r + T & \text{for} \quad p_a > u \\ r - (u - p_a) + T & \text{for} \quad p_a \leq u, p_c > u \\ r + (p_a - p_c) + T & \text{for} \quad p_a \leq p_c \leq u. \end{cases} \tag{14}$$

Let $\overline{\eta}$ denote the difference between the generalized prices, η, and travel cost, T, that is, $\overline{\eta} = \eta - T$. Passenger demand is now determined by the equilibrium condition $B' = \overline{\eta}(r, p_a, p_c)$ leading to demands $D'(\overline{\eta}(r, p_a, p_c)) = 1/B''$; thus, in this scenario, passenger demand depends on the airport charge as well as the ancillary price and the city-center price because the generalized price of traveling is determined by all these prices. Ancillary and city-center demands, can be obtained by substituting $D(r)$ by $D(\overline{\eta}(r, p_a, p_c))$ in (1) and (2), respectively. Similarly, substituting $D(r)$ by $D(\overline{\eta}(r, p_a, p_c))$ in profits (3) and (4) yields airport and city-center profits for the case of foresighted passengers.

Best responses and equilibrium prices are derived analogously to the previous section that concentrated on myopic passengers.

4.1 Best responses

Airport charge. The derivation of the best responses in terms of the airport charge when passengers are foresighted is analogous to the case of myopic passengers. These best responses can be obtained by substituting $D(r)$ by $D(\overline{\eta}(r, p_a, p_c))$ in the best responses in (5). The only difference between the cases with foresighted and myopic passengers is that the demand of foresighted passengers exceeds the demand of myopic passengers, that is, $D(\overline{\eta}(r, p_a, p_c)) > D(r)$, when $p_a \leq \min\{u, p_c\}$ because foresighted passengers take into account that the ancillary price is lower than the city-center price and therefore expand traveling activities in order to benefit from the price discount at the airport.

Ancillary price. While foresighted passengers leave best responses in terms of airport charges largely unchanged relative to myopic passengers, best responses in terms of the ancillary price are strongly affected by foresightedness. It is useful to distinguish six cases.

The first case is characterized by $(p_c > u) \cap (T - D/D' - u > r > -D/D' - u)$. In this case, the city-center demand is zero, while airport profit can be written as $\Pi_a = (r + p_a)\, D$, where D is determined by $B' = r - (u - p_a)$. The best ancillary price response implied by the first-order condition $\partial \Pi_a / \partial p_a = 0$ can be written as $p_a^{br} = -D/D' - r$. The right-hand side is decreasing in the infrastructure price, which shows that the airport reduces its ancillary price to boost passenger demand if the infrastructure price is positive. The upper and lower limits on r, $T - D/D' - u$ and $-D/D' - u$, respectively, ensure that p_a^{br} is less than the ancillary utility u but higher than the ancillary price $p_a = u - T$, which would encourage non-travelers to visit the airport only for shopping reasons.

The second case is characterized by $(p_c > u) \cap (r \geq T - D/D' - u)$. This is similar to the previous case, except that the candidate for an interior best response, $p_a^{br} = -D/D' - r$, is lower than $u - T$ and, thus, would encourage non-travelers to visit the airport only for shopping reasons, which would lead to airport profit $\Pi_a = rD + p_a Q$. Recall that the city population, Q, approaches infinity by Assumption 1. This means that an airport ancillary price lower than $u - T$ only leads to negative airport profit and that, therefore, the best response must be to set a price that is higher than $u - T$.

The third case is characterized by $(p_c > u) \cap (r < -D/D' - u)$, which implies airport profit $\Pi_a = (r + p_a)\, D$, where D is determined by the equilibrium condition $B' = r - (u - p_a)$. In this case, the city-center demand is, again, zero. This case implies, $\partial \Pi_a / \partial p_a = (r + p_a)\, D' + D > 0$, which means that the airport profit increases in the ancillary price p_a and implies the corner solution $p_a^{br} = u$. The infrastructure price is so low in this case that the sum of the prices $r + p_a$ cannot reach the global profit maximizing level $-D/D'$ because the best response for the ancillary price p_a is limited from above by the good's utility u.

The fourth case is characterized by $(p_c \leq u) \cap (T - D/D' - p_c > r \geq -D/D' - p_c)$, which implies airport profit $\Pi_a = (r + p_a)\, D$, where D is determined by $B' = r - (p_c - p_a)$. The ancillary price response implies $r + p_a^{br} = -D/D'$ when $r \geq -D/D' - p_c$ (which ensures that this best response is smaller than the price of the city-center rival p_c), which leads to passenger demand $D(r, p_a^{br}, p_c) = -D/D'$. In the present case, non-travelers visit the airport only for shopping reasons when $p_a = p_a^{br}$, which is ruled out by $r < T - D/D' - p_c$.

The fifth case is characterized by $(p_c \leq u) \cap (r \geq T - D/D' - p_c)$. This is similar to the second case, and Assumption 1 implies that the ancillary price response exceeds the lower limit, $p_c - T$, that

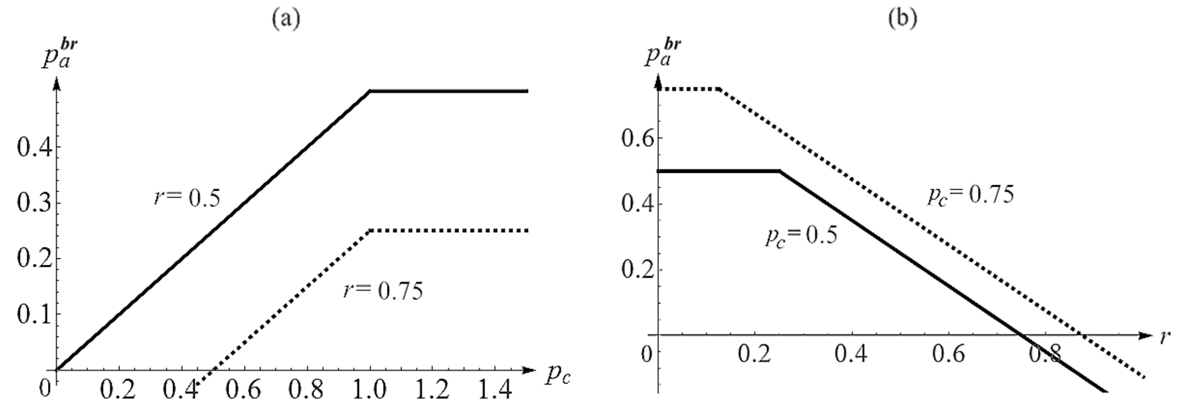

Figure 4: Best responses in terms of p_a for given airport charge r , part (a), or given city-center price p_c, part (b)

is, $p_a^{br} \geq p_c - T$, to ensure that non-travelers will consume in the city-center.

The sixth case is characterized by $(p_c \leq u) \cap (r < -D/D' - p_c)$, which implies airport profit $\Pi_a = (r + p_a) D$, where D is determined by $B' = r - (p_c - p_a)$. In this case the first derivative of profit depending on p_a yields $\partial \Pi_a / \partial p_a = (r + p_a) D' + D > 0$, which means that the airport profit function is, again, increasing in the ancillary price p_a. In this case, the infrastructure price is, again, so low that the sum of the prices $r + p_a$ cannot reach the global profit-maximizing level $-D/D'$ because the best response for the ancillary price p_a is limited from above by the city-center price p_c, which is less than the good's utility in this case.

Altogether, for foresighted passengers and given city-center price p_c and airport charge r, the airport's best responses in terms of the ancillary price p_a can be written as

$$p_a^{br}(r, p_c) = \begin{cases} -D/D' - r & \text{for} \quad (p_c > u) \cap (T - D/D' - u > r \geq -D/D' - u) \\ \geq u - T & \text{for} \quad (p_c > u) \cap (r \geq T - D/D' - u) \\ u & \text{for} \quad (p_c > u) \cap (r < -D/D' - u) \\ -D/D' - r & \text{for} \quad (p_c \leq u) \cap (T - D/D' - p_c > r \geq -D/D' - p_c) \\ \geq p_c - T & \text{for} \quad (p_c \leq u) \cap (r \geq T - D/D' - p_c) \\ p_c & \text{for} \quad (p_c \leq u) \cap (r < -D/D' - p_c) . \end{cases} \tag{15}$$

Best responses in terms of the ancillary price are illustrated in the following example.

Example 4 *Figure 4 is composed of parts (a) and (b), which are used to illustrate the best responses in terms of p_a for parameters $T = 2$ and $a = u = 1$ depending on p_c and r, respectively. Part (a) considers $r = 1/2$ (solid line) and $r = 3/4$ (dashed line) as given. In these cases, the best responses in terms of the ancillary price p_a is increasing in p_c for values of the city-center price less than the good's utility, that is, for $p_c < u$. The ancillary price response is always less than the city-center price, which shows that the airport charges a relative low ancillary price to boost passenger demand. Part (b) considers $p_c = 1/2$ (solid line) or $p_c = 3/4$ (dashed line) as given. For $r < -D/D' - p_c$,* *the airport charges an ancillary price that is equal to the city-center price because boosting passenger demand by reducing the ancillary price does not payoff at such low levels of the infrastructure price. For $r \geq -D/D' - p_c$, boosting the passenger demand by reducing the ancillary price is a sensible strategy for the airport, which explains why the ancillary price response is decreasing in the airport charge.*

Airport charge and ancillary price. Consider the simultaneous choice of the airport charge and ancillary price. These best responses are defined by the maximization problem in (7) for $D = D(\overline{\eta}(r, p_a, p_c))$ and derived by deletion of dominated strategies. For instance, best responses in (15) imply that the ancillary price will never (strictly) exceed the minimum of the good's utility and city-center price, $\min\{u, p_c\}$, and the airport will never charge an ancillary price that encourages non-travelers to visit the airport only for shopping reasons, that is, $p_a^{br} \geq \min\{u, p_c\} - T$. Using this information, best responses in terms of the airport charge imply that the sum of the best responses in terms of the airport charge and ancillary price satisfy $(r(p_c) + p_a(p_c))^{br} = (-D/D' + \min\{p_c, u\})/2$. For foresighted passengers and given city-center price, $p_c \geq 0$, the airport's best responses in terms of the airport charge and the ancillary price can altogether be written as

$$(r(p_c), p_a(p_c))^{br} = \left\{(r, p_a) : (\min\{u, p_c\} \geq p_a > \min\{u, p_c\} - T) \cap \left(r + p_a = -D/D'\right)\right\} \quad (16)$$

The best responses in (16) show that the best responses in terms of the airport charge and ancillary price are highly interdependent and possibly involve a negative, that is, loss-making ancillary price.[15] This is because the sum of airport prices matter to passengers, while changes in the structure of airport prices may have no effect on passenger and ancillary demands at all. This is a big difference relative to the scenario with myopic passengers where best responses are unique.

City-center price. Best responses in terms of city-center goods depend only on the city-center price no matter whether passengers are myopic or foresighted. The best responses in (10) therefore also hold under the current conditions with foresighted passengers.

4.2 Equilibrium pricing strategies and welfare evaluation

City-center best responses in (10) and airport best responses in (16) together with Assumption 1, imply that the set of equilibria in (pure) pricing strategies that exist in the case of foresighted passengers can be characterized as follows. Assumption 1 implies $\widetilde{p} = u$. In this case, the second line on the right-hand side of the city-center best response implies $p_c^{br} = u$ for $u - T \leq p_a < u$. Plugging a city-center price u into equation (16), equilibrium airport charge and ancillary price can be characterized by $r^N + p_a^N = -D/D'$ for $u - T \leq p_a < u$. Altogether, this implies:

[15] Gomes and Tirole (2018) propose the banning pricing policies that involve loss-making on the ancillary goods.

Proposition 5 *For foresighted passengers and given Assumption 1, there exists a set of equilibria in pure pricing strategies, which can be described by* $\{(r^N, p_a^N) : r + p_a = -D/D', u - T \leq p_a < u\}$ *and* $p_c^N = u$.

While equilibrium airport charges are uniquely defined when passengers are myopic, only the sum of the airport charge and the ancillary price is uniquely defined when passengers are foresighted, while the values of the airport charge and the ancillary price are undetermined. It is therefore unclear how foresightedness affects the equilibrium airport charge relative to the case of myopic passengers. However, while ancillary supply will unambiguously reduce the equilibrium airport charge in the case of myopic passengers, the set of equilibrium prices imply that the ancillary supply can increase the equilibrium airport charge relative to the case without ancillary supply. Consider $p_a^N = 0$. In this case $\overline{\eta} = r - u$ and $D(r - u) > D(r)$ by the concavity of the benefit function B, where the larger demand leads to an increase in the monopoly airport charge if the demand function is sufficiently concave.[16]

In the case of foresighted passengers, welfare given by (13) is maximized when $\overline{\eta}(r, p_a, p_c) = 0$, $p_c - T \leq p_a \leq u$ and $p_c \leq u$. The difference relative to the case with myopic passengers is that the generalized price is represented by $\overline{\eta}(r, p_a, p_c)$ and not only the airport charge r. Thus, if $p_c = p_c^N$, welfare-maximization requires $\overline{\eta}(r^N, p_a^N, u) = r^N + p_a^N - u = 0$. As for myopic passengers, where the generalized price of traveling is determined by the airport charge, the welfare-maximizing generalized price of traveling is equal to zero and therefore does not contain a negative term that is used to increase passenger numbers and boost non-aeronautical airport businesses. Using Proposition 5 and substituting $r^N + p_a^N$ by $-D/D'$ in the middle implies:

Proposition 6 *For foresighted passengers and given Assumption 1, equilibrium airport and city-center prices maximize welfare if* $u = -D/D'$ *in equilibrium, while passengers quantities are excessive or too low from the social viewpoint if* $u > -D/D'$ *or* $u < -D/D'$ *in equilibrium, respectively.*

Recall that with myopic passengers the equilibrium airport charge depends on the good's utility u, while the welfare-maximizing airport charge was independent of u, which explained why equilibrium and welfare-maximizing behaviors could lead to the same pricing outcomes. With foresighted passengers, the picture changes. In this case, the equilibrium sum of airport prices is fully determined by the absolute value of the inverse semi-price elasticity, $-D/D'$, and in this sense independent of u, while the welfare-maximizing generalized price depends on u. Thus, in the case of foresighted passengers, consistency between equilibrium and welfare-maximizing behavior is achieved by the affect of u on the welfare-maximizing generalized price, which is in contrast to the case with myopic passengers where adjustments occur by the effect of u on the equilibrium airport charge.

Comparison of Propositions 4 and 6 directly reveals:

[16] See Vives (1999) for a discussion of how the curvature of demand functions affect profit-maximizing prices.

Theorem 5 *Given Assumption 1 it holds that the welfare-evaluation of equilibrium airport charges and ancillary prices is independent of whether passengers are myopic or foresighted.*

Starkie (2001) used a graphical analysis to illustrate that profit-maximizing airport pricing behavior should be of no concern to policy makers because airports would reduce the airport charge in order to boost passenger demand and ancillary businesses. Czerny (2006) showed numerically that the opposite, that is, airports reduce ancillary prices to boost passenger demand and aeronautical revenues, can be true in the case of foresighted passengers. Czerny (2009 and 2013) showed that profit-maximizing airport charges can be welfare-maximizing if airport non-aeronautical businesses are welfare-neutral in the sense that the aggregate consumption of the good inside and outside the airport area can be independent of traveling activities. He also concentrated on foresighted passengers but assumed exogenous differences between ancillary and city-center prices. Kidokoro, Lin and Zhang (2016) did not explicitly distinguish between myopic and foresighted passengers and reproduced this result in a context with perfect competition where, because of perfect competition, the generalized prices for ancillary and city-center supplies are equalized. Theorem 5 shows that the policy evaluation of equilibrium profit-maximizing airport charges is, given Assumption 1, independent of whether passengers are myopic or foresighted although for different reasons: with myopic passengers it is the profit-maximizing aeronautical charge that is affected by ancillary businesses, while with foresighted passengers it is the generalized price of traveling that is affected by ancillary businesses. Altogether, this means that policy makers may not need to worry about the foresightedness of passengers in their assessment of airport privatization policies.

Several strong assumptions are employed in the present analysis until now. The following section develops and analyzes various model extensions to analyze the robustness of the independence result by relaxing some of these assumptions.

5 Extensions

This section extends the basic model by capturing downward sloping demands for ancillary and city-center supplies, the effects of the economic regulation of airport charges, preferences for ancillary relative to city-center goods, and airline market power. The extensions are separately addressed in following four subsections.

5.1 Downward sloping individual demands for the good

The basic model assumes that every individual consumes at most one unit of the good. This part extends the basic model by capturing that the individual consumption of the good can be decreasing in the good's price.

Let x denote the individual consumption of the good and b with $b = b(x)$ denote the strictly concave individual benefit from the consumption of the good. Individual demand depending on the price p_i with $i = a, c$, denoted by δ with $\delta = \delta(p_i)$, is determined by the equilibrium condition $b' = p_i$ leading to $\delta'(p_i) = 1/b'' < 0$, which shows that individual demands are downward sloping in the good's prices by the strict concavity of b. The profit per individual can be written as $p_i\delta(p_i)$. The corresponding profit-maximizing price, denoted by $\widehat{p}$, is determined by the first-order condition $\delta + \widehat{p}\delta' = 0$, which implies $\widehat{p} = -\delta/\delta'$ and profit $-\delta^2/\delta'$.[17] Consider $u \equiv -\delta^2/\delta'$. This implies that the equilibrium pricing results for airport and city-center prices and the welfare evaluation of airport charges in the case of myopic passengers mentioned in Propositions 3 and 4, respectively, are robust and carry over to the case of downward sloping individual demands for the good.

Downward sloping individual demands for the goods still matter in the case of myopic passengers. While the good's welfare-maximizing price is not unique in the case of unit demands for the good where any prices $p_a, p_c \leq u$ ensure a welfare-maximizing consumption of the good, zero ancillary and city-center prices are required for welfare-maximization in the case of downward sloping demands. The welfare evaluation of equilibrium pricing strategies therefore changes by the presence of downward sloping individual demands for the good because the equilibrium prices $\widehat{p}$ are excessive from the social viewpoint, while equilibrium prices for the good are welfare-maximizing in the case of unit demands.

In the case of foresighted passengers, equilibrium pricing behavior is strongly affected by downward sloping individual demands for the good. To see this, denote the consumer surplus from the good's consumption by $cs(p_i)$ with $cs(p_i) = b(\delta(p_i)) - p_i\delta(p_i)$, and observe that the generalized price of traveling, $\overline{\eta}$, can be written as

$$\overline{\eta}(r, p_a, p_c) = r - (cs(p_a) - cs(p_c)) \tag{17}$$

for $p_a \leq p_c$ and T large enough to discourage individuals to travel to the airport only for shopping reasons.[18] The right-hand side shows that, in this case with $p_a \leq p_c$, the passengers' traveling decisions depend on the airport charge and also on the difference in the consumer surpluses (not the difference in prices as with unit demands) that can be achieved by the consumption of ancillary and city-center goods. The right-hand side further shows that the airport can reduce the ancillary price and internalize the associated increase in the consumer surplus $cs(p_a)$ by a corresponding increase in the airport charge. As shown by Czerny and Lindsey (2014) for the case of a monopoly firm, this constellation leads to a profit-maximizing ancillary price, called side price in their context, of zero.[19]

[17] Log-concavity of demand, δ, is assumed to ensure the existence of a profit-maximizing price.

[18] With foresighted passengers $T > (cs(0) - cs(\widehat{p}))$ ensures that individuals will not travel to the airport only for shopping reasons.

[19] The optimality of a zero price can be related to Oi's (1971) famous result that zero marginal prices can be profit-maximizing in a two-part tariffs framework. In our case, the airport charge can have the interpretation of a fixed fee, while the ancillary price can have the interpretation of the marginal price (Czerny and Lindsey, 2014). Zero prices for ancillary supplies are common in many industries (for example, Fruchter, Gertsner, and Dobson, 2011).

The city-center company will still charge a monopoly price $\widehat{p}$ because it only offers the city-center good, which makes internalization of consumer surplus as practiced by the airport difficult. This shows that ancillary supply can be welfare-improving in the sense that it leads to a welfare-maximizing ancillary price of zero, which is lower than the city-center price. Equilibrium airport profit therefore reduces to $\Pi_a = rD$, and leads to the profit-maximizing price $-D/D'$. Examples for zero ancillary prices can be the supply of free airport wifi services, free drinking water supply in terminals and gratis supply of electricity for laptop computers and work spaces.

In the case of foresighted passengers, also the welfare-maximizing airport charge changes. Conditional on equilibrium ancillary and city-center prices, which implies ancillary consumption $q\delta(0)$ and city-center consumption $(Q-q)\delta(\widehat{p})$, welfare can be written as

$$W(q, q_a, q_c) = W(q, q\delta(0), (Q-q)\delta(\widehat{p})) = B(q) + qb(\delta(0)) + (Q-q)\, b(\delta(\widehat{p})). \tag{18}$$

The second and the third terms on the right-hand side capture that individual ancillary consumption exceeds individual city-center consumption in equilibrium. The welfare-maximizing passenger quantity, conditional on equilibrium ancillary and city-center prices, are given by the first-order condition $B' + b(\delta(0)) - b(\delta(\widehat{p})) = 0$, where the sum of the second and the third terms on the left-hand side is positive. This implies that, in the present scenario with foresighted passengers and individual downward sloping demands for the good, the welfare-maximizing generalized price of traveling is negative. Thus, this scenario is consistent with the findings by Zhang and Zhang (2010) and Kidokoro, Lin and Zhang (2016), who found that generalized prices of traveling can be negative due to the supply of non-aeronautical businesses. However, our result is based on differences in equilibrium ancillary and city-center prices, which are absent in their approach.

Using $b(\delta(0)) = cs(0)$, equilibrium prices are therefore welfare-maximizing if the generalized price of traveling satisfies the condition

$$-D'/D - (cs(0) - cs(\widehat{p})) = b(\delta(\widehat{p})) - cs(0). \tag{19}$$

The left-hand side is the equilibrium generalized of traveling and the right-hand side determines the welfare-maximizing generalized price. If $-D'/D = -\delta^2(\widehat{p})/\delta'(\widehat{p})$, equilibrium airport charges are welfare-maximizing conditional on equilibrium ancillary and city-center prices.

Altogether, this shows that Theorem 5 is robust in the sense that the welfare evaluation of equilibrium airport charges is the same for myopic and foresighted passengers independent of whether unit or downward sloping individual demands for the good are considered. The presence of myopic or foresighted passengers still makes a difference because the equilibrium ancillary and city-center prices are excessive from the welfare viewpoint when passengers are myopic, while only city-center prices are excessive from the welfare viewpoint when passengers are foresighted.

5.2 Price regulation

Airports worldwide generate more than 20 percent of their non-aeronautical revenues by car parking (Airports Council International, 2015). This seemingly contradicts the result that airports use ancillary businesses primarily to boost the demand of foresighted passengers and aeronautical businesses. One reason for this discrepancy may be that some airports are under private ownership and price regulated in a way that limits airport infrastructure charges from above (for example, Bilotkach et. al, 2012; Czerny, 2006; Czerny and Forsyth, 2008; Czerny, Guiomard and Zhang, 2016; Kratzsch and Sieg, 2011; Lu and Pagliari, 2004; Yang and Zhang, 2011 and 2012).[20] To understand how price regulation in the form of upper limits (so called price-caps), denoted by $\overline{r}$, affects airport pricing behavior assume that the airport chooses airport charges under the regulatory constraint $r \leq \overline{r}$ and that $u < -D/D'$. The latter ensures that the equilibrium passenger quantities are too low from the social viewpoint despite the existence of ancillary businesses independent of whether passengers are myopic or foresighted.

Consider myopic passengers with unit demands for the good. In this case, the welfare-maximizing airport charge is zero, $r = 0$. Price-cap regulation can indeed be welfare-enhancing under these conditions because it can help to increase passenger quantities that are too low in the absence of price-cap regulation. The same is true for the case of foresighted passengers and unit demands. Based on the equilibrium prices in Proposition 5, the price-cap will be binding and reduce the equilibrium airport charge only if it implies $r + p_a < -D/D'$, where $u < -D/D'$ is a sufficient condition for this to happen because u imposes an upper limit on the equilibrium ancillary price.

Consider individual downward sloping demands for the good. In the case of myopic passengers, the effect of price-cap regulation is largely unaffected by the presence of downward sloping individual demands for the good. The price-cap will be binding and reduce the equilibrium airport charge for $\overline{r} < -D/D' - \delta^2/\delta'$, and price-cap regulation can enhance social welfare only if ancillary businesses are small enough in the sense that $-\delta^2/\delta' < -D/D'$. However, in the case of foresighted passengers, price-cap regulations can have a more significant impact. In this case, full internalization of the consumer surplus derived from ancillary goods consumption is not ensured, which is a condition for the profit-maximizing ancillary price to be equal to the socially optimal ancillary price of zero. Thus, while price-cap regulation can reduce the airport charge under these conditions, it will increase the profit-maximizing ancillary price. This provides one possible explanation for the discrepancy between the results described in the previous subsection and real-world airport pricing and revenue structures.

5.3 Preference for ancillary over city-center supply

The basic model assumes that the good's consumption utilities are equal for ancillary and city-center goods. This seems a strong assumption in some contexts. For example, passengers may prefer car

[20] More than 50 percent of European airports are under public ownership (Airports Council International, 2017). Public ownership is even more common in the US and Asia.

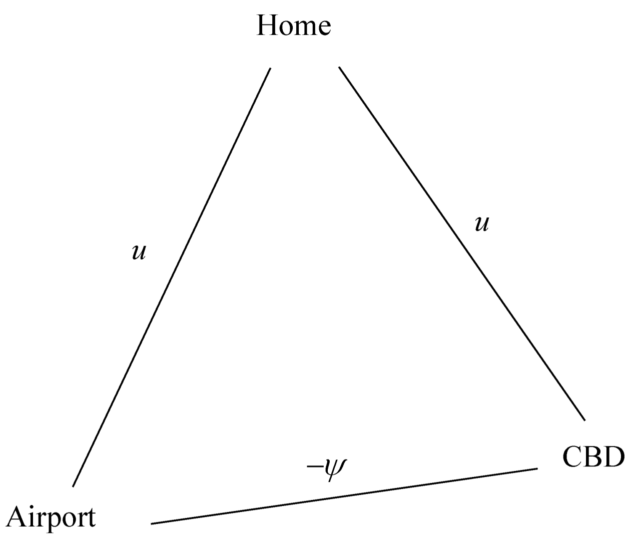

Figure 5: Airport versus city-center utilities

parking services inside the airport area relative to car parking services outside the airport area (Kidokoro, Lin and Zhang, 2016). Another example is related to the availability of goods and services before and after security, which may be perceived as different. For instance, passengers may want to consume food and beverages before departure and not carry sandwiches bought in the city-center to the departure gate and consume them over there.

Figure 5 illustrates. The figure displays a home location as well as the central business district's and the airport's locations. If the individual does not travel, she shops in the city-center and the utility from city-center car parking is given by u. If she flies, she travels to the airport and parks at the airport, which also yields utility u. However, if she flies and parks in the city-center, the car parking utility is reduced by ψ because the city-center car park is far from the airport, which is inconvenient relative to a car park inside the airport area. In this scenario, undercutting is more difficult for the city-center company. This is true in the sense that, independent of whether passengers are myopic or foresighted, an equilibrium in pure-pricing strategies with $p_a = u$ exists for a large enough city-population in the sense that $Q > Du/\psi$. Recall that the existence of such an equilibrium pricing strategy required an infinite city population with homogenous ancillary and city-center goods. The city-population requirement is, thus, relaxed under the current conditions with a preference for ancillary over city-center supply where a finite city population is sufficient to ensure the existence of an equilibrium in pure pricing strategies.

5.4 Airline market power

The basic model assumed that airline markets are atomistic so that the airport charge and ticket prices are equal. Airports are usually dominated by only a few carriers, each of which runs a large number of flights at the airport and has market power (for example, Borenstein, 1989; Daniel, 1995; Brueckner, 2002; Zhang and Czerny, 2012). In this situation, where airlines have market power, carriers can charge a premium on the airport charge denoted by $\chi(n)$ with $\lim_{n\to\infty}\chi(n)=0$ so that the ticket price exceeds the airport charge in equilibrium. Pels and Verhoef (2004) pointed out that airport subsidy payments to airlines are needed to correct for airline market power and achieve the socially optimal passenger quantity. To capture this, the benefit function can be rewritten as $\overline{B}(q)=B(q)+q(T+\chi(n))$ and the generalized price of traveling can be rewritten as $\eta=r+T+\chi(n)$. With this remodeling, the analyses in Sections 3 and 4 and the results still hold true with the exception that the welfare-maximizing airport charges must be less than zero and equal to $-\chi(n)$ to correct for airline market power.

6 Conclusions

The present study considered a profit-maximizing airport that competes with a city-center company in the area of ancillary good supply. The results showed that equilibrium pricing strategies depend critically on the size of the city population. Equilibrium pricing strategies were derived for the cases of myopic and foresighted passengers and evaluated from the welfare viewpoint conditional on the assumption that a small fraction of the city population is present at the airport at a specific point in time.

In both cases and with unit demand for the good, equilibrium pricing behavior can be welfare-maximizing under the exact same parameter conditions (we called this the "independence result"). In the case of myopic passengers, profit- and welfare-maximizing prices can coincide because the equilibrium airport charge is decreasing in the ancillary profit per passenger, whereas the welfare-maximizing airport charge is independent of the ancillary profit per passenger. In the case of foresighted passengers prices can coincide because the welfare-maximizing generalized price of traveling depends on the ancillary profit per passenger. The independence result indicates that policy makers may not need to worry about the foresightedness of passengers in their assessment of airport privatization policies.

The independence result can be helpful for policy makers because the assessment of whether passengers are myopic or foresighted represents a challenging task. Empirical evidence suggests that passengers may indeed be foresighted (see, Czerny, Shi and Zhang, 2016). The issue is however far from resolved, and the assumption of myopic passengers is popular among transport economists. The independence result indicates that the welfare assessment of profit-maximizing airport charges for aeronautical and non-aeronautical supplies can be independent of whether passengers are myopic or foresighted. Therefore, policy makers may simply assume that passengers are myopic, which often simplifies the analysis, and assess the situation under this simplifying assumption. Given the independence result, the result of this assessment would then be robust in the sense that the assessment result would remain unchanged even for the more complicated case of foresighted passengers.

An extended version of the basic model captured the case of downward sloping individual demands for ancillary and city-center goods. This extension was used to show that the independence result carries over to the case of downward sloping individual demands for the good in the following sense: the welfare evaluation of equilibrium airport charges is the same for myopic and foresighted passengers independent of whether unit or downward sloping individual demands for the good are considered. A result that does not carry over from unit to downward sloping individual demands is related to the welfare evaluation of equilibrium ancillary prices. While equilibrium ancillary prices are excessive when individual demands for the good are downward sloping and passengers are myopic, they are welfare-maximizing when individual demands for the good are downward sloping and passengers are foresighted. However, this result, the welfare-optimality of equilibrium ancillary prices when individual demands for the good are downward sloping, depends strongly on the absence of the regulation of airport charges. More specifically, we showed that price regulation limits the possibility to internalize the consumer surplus associated with the consumption of the ancillary good, which reduces the airport's incentives to reduce the ancillary price.

Other extensions covered cases where ancillary supply is preferred over city-center supply by passengers (for example, car parking inside the airport area over car parking outside the airport area) and airlines have market power. These extensions are used to point out that city-size assumptions can be relaxed and that the welfare-maximizing pricing structure can be affected by airline market power, respectively.

There are several avenues for future research. The present study concentrated on an airport with two supplies and a city-center company with only one supply. This was to concentrate on airport businesses and ensure the tractability of the model. However, also city-center businesses typically supply multiple products and services, and it would be interesting to see how multiple city-center supplies would affect equilibrium airport and city-center pricing behavior. Another simplification of our model is the consideration of only myopic or only foresighted passengers. A worthwhile model extension could include a mix of myopic and foresighted passengers.

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Appendix

A Proof of Proposition 2

Let $F_a(p_c)$ denote the cumulative distribution function that represents the mixed strategy of the airport in terms of its ancillary price. The expected profit of the city-center company can be written as

$$\theta = F_a(p_c)p_c\,(Q-D) + (1-F_a(p_c))\,p_cQ, \tag{a.1}$$

where θ denotes a constant. The first term on the right-hand side shows the city-center profit if the ancillary price is lower than the city-center price weighted by the probability that this situation occurs. The second term on the left-hand side shows the city-center profit if the ancillary price exceeds the city-center price weighted by the probability that this situation occurs. Solving for the cumulative distribution function yields

$$F_a(p_c) = \frac{p_cQ-\theta}{p_cD}. \tag{a.2}$$

The upper support of this cumulative distribution function is $p_a = u$, which implies $F_a(u) = 1$ and $\theta = u \cdot (Q-(a-r))$. Altogether, this implies the airport's atomless mixed pricing strategy

$$F_a(p_c) = \begin{cases} 0 & \text{for} \quad p_c \leq \widetilde{p} \\ \frac{p_cQ-u(Q-D)}{p_cD} & \text{for} \quad \widetilde{p} \leq p_c \leq u \\ 1 & \text{for} \quad p_c \geq u. \end{cases} \tag{a.3}$$

Let $F_c(p_a)$ denote the cumulative distribution function that represents the mixed strategy of the city-center company. Since the city-center company should never charge a price below $\widetilde{p}$, the airport can secure a profit of $(\widetilde{p}+r)\cdot D$ by charging a price slightly below $\widetilde{p}$. The city-center's mixed pricing strategy must therefore satisfy the indifference condition

$$F_c(p_a)rD + (1-F_c(p_a))\,(r+p_a)\,D = (\widetilde{p}+r)\,D, \tag{a.4}$$

in equilibrium. The first (second) term on the left-hand side shows the profit when the city-center company charges a price that is lower (higher) than the ancillary price weighted by the probability that this happens. The right-hand side shows that profit airport can secured by charging a price slightly below $\widetilde{p}$. Solving for the cumulative distribution function $F_c(p_a)$ leads to

$$F_c(p_a) = \begin{cases} 0 & \text{for} \quad p_a \leq \widetilde{p} \\ 1-u\frac{Q-D}{p_aQ} & \text{for} \quad \widetilde{p} \leq p_a < u \\ 1 & \text{for} \quad p_a = u. \end{cases} \tag{a.5}$$

This equilibrium mixed strategy involves an atom because the probability that the city center charges a price equal to u is given by $(Q-D)/Q$ in equilibrium, which approaches 1 when Q approaches infinity.