



Contents lists available at ScienceDirect

Journal of Air Transport Management

journal homepage: www.elsevier.com/locate/jairtraman

Is developing air cargo airports in the hinterland the way of the future?

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ARTICLE INFO

Article history:

Received 30 November 2015

Received in revised form

5 September 2016

Accepted 26 September 2016

Available online xxx

ABSTRACT

In this paper, we provide an analytical framework to capture the competition (and cooperation) between gateway and hinterland airports. We first investigate how airport charges at gateway and hinterland airports affect the equilibrium output in passenger and cargo markets. We further consider the Pearl River Delta region in China as a setting to conduct a numerical analysis. We find that the introduction of a hinterland airport is likely to lead to an improvement in the aggregate welfare of the gateway and the hinterland. If the connectivity between the gateway and hinterland airports is improved, then social welfare at the gateway and hinterland, benefits for shippers and passengers, and airport and airline profits at the gateway airport will increase. However, airport and airline profits at the hinterland airport will decrease.

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1. Introduction

For decades, major airports around the world have predominantly served passenger markets (Mayer, 2016), and thus their operations and infrastructure were designed primarily to meet the needs of passengers.¹ Such airports are also referred to as “gateway airports”.² Most gateway airports (and airlines) serve passengers first, with their remaining capacity serving air cargo. This phenomenon can be attributed to the fact that the volume of air cargo is not sufficiently large to reach a critical mass. To a great extent, air cargo plays a complementary role for passengers, filling the excess capacity of aircraft.

Along with cargo growth at gateway airports, costs in the gateway cities have been increasing (reality in most international cities). Consequently, manufacturing and logistics enterprises

relocate further into the hinterland, resulting in a growing distance between the manufacturing base and the gateway airport.³ The longer travel times and added complexities in logistics management are not conducive to the efficient and timely delivery of goods. This expansion creates potential problems for shippers who might look for alternative gateways, modes of transport or relocate their factories in the long run. In response, some governments have built airports in their respective hinterlands – referred to as “hinterland airports” in this paper – dedicated to the transport of airfreight,⁴ as hinterland airports can leverage the comparative advantage of their proximity to shippers.⁵ Because of the emphasis on freight, most airlines in hinterland airports use airfreight-

³ A typical example is the relocation of the manufacturing base from Hong Kong to the PRD Region in China. Additional discussion can be found in Sung (1998) and Zhang (2003).

⁴ Instead of building new airports, airfreight-dedicated airports may be transformed from some secondary passenger airports in the hinterland.

⁵ In addition to the related to cross borders (see our specific case of Hong Kong-Shenzhen discussed below; and Zhang, 2002), a possible advantage for a hinterland airport to specialize in cargo business is that freedoms of air for cargo are easier to obtain in the bilateral negotiation. For example, air service agreements of Taiwan, the Philippines, Brunei, and Singapore with the US include seventh-freedom traffic rights for cargo. Given the difficulties in liberalizing of the air passenger sector, it has been suggested that the air cargo rights should be liberalized first, through the multilateral services liberalization program of the General Agreement on Trade in Services (GATS) (Zhang and Zhang, 2002a).

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¹ Mayer (2016) identified 17 major international primary hub airports, where cargo is produced mainly as a “by-product” of their passenger operations.

² Many major airports, including Hong Kong, Frankfurt and Singapore, can be considered gateway airports in that they serve as international outlets for passengers and air cargo from their regions. Such gateway airports handle two kinds of flows: gateway flows and hub flows (Zhang, 2003). Gateway flows are traffic that move between the gateway and the hinterland via surface transportation. Hub flows use the gateway airport as a hub for other airports (so-called “air to air” flow).

dedicated aircraft (e.g., Boeing's 747-400F/ERF and 777F) but not combination flights, focusing on passenger traffic with cargo traffic as a side business. Therefore, airline operations at hinterland airports might lack synergy between their passenger and cargo businesses, and network coverage may be less comprehensive than that of gateway airports.

In this paper, we develop an analytical model to examine the social benefits of introducing hinterland airports and to analyze the competition and collaboration between the gateway and hinterland airports. The model captures the following features: demand and cost complementarities for the passenger and cargo markets, airline competition, hub/gateway premiums, and intermodal connections. A numerical analysis is conducted using real-life data from the Pearl River Delta (PRD) region in China, where the Hong Kong airport serves as a gateway airport and the Shenzhen airport serves as a hinterland airport. We investigate the following questions: What are the welfare implications of introducing a cargo-dedicated airport in the hinterland for different stakeholders? Should the gateway and hinterland airports cooperate or compete with each other from the social-welfare point of view? How do coordination and competition affect the benefits of the various stakeholders?

From the analytical results, we find that an increase in the charges of an airport decreases its air cargo output but increases the output of the other airport. Furthermore, an increase in gateway airport charges, imposed on either passengers or cargo, decreases passenger output. However, an increase in the cargo airport charge at the hinterland airport increases passenger output at the gateway airport. In the numerical analysis with data for the Hong Kong and Shenzhen airports, we find that the introduction of the hinterland airport likely leads to an improvement in the aggregate welfare of both the gateway and the hinterland. However, after the introduction of a hinterland cargo airport, shippers may be either better off or worse off, depending on a number of factors, including transportation costs, airport charges, demand complementarity between passengers and cargo, scale and scope economies of cargo and passenger operations. Finally, we find that if coordination between gateway and hinterland airports leads to improved connections between the two regions, the social welfare is also improved. In particular, with respect to the gateway and hinterland airports, the shippers and passengers and the airports and airlines at gateway airports will benefit from it, while the airport and airline profits at hinterland airports will decrease. In addition, there will be an increase in the gateway cargo output and the total cargo output, while the hinterland cargo output will decrease.

The remainder of this article is organized as follows. Section 2 reviews the literature. Section 3 sets up the general analytical model, and Section 4 derives analytical results for the gateway and hinterland airport networks using specific functional forms. Section 5 conducts the numerical analysis, and Section 6 discusses policy and managerial implications from the numerical analysis. Finally, Section 7 contains concluding remarks.

2. Literature review

Our work is related to three branches of literature. First, the operation of combination flights has attracted a significant amount of attention in the literature (e.g., Zhang and Zhang, 2002b; Slager and Kapteijns, 2004; Zhang et al., 2004, 2007; Sandhu and Klabjan, 2006; Tang et al., 2008; Wong et al., 2009). In particular, the benefits of operating combination flights have long been recognized (e.g., Gillen et al., 1990; Antoniou, 1991; Zhang and Zhang, 2002b; Hong and Zhang, 2010; Hofer and Eroglu, 2010; Kupfer et al., 2014, 2016). Accordingly, passenger airlines' profitabilities increase with cost volumes, suggesting that complementarities

between passenger and cargo may exist (Antoniou, 1991). Hong and Zhang (2010) found that airlines with a high share of cargo business in their overall operations are significantly more efficient than airlines with a low share of cargo business. Kupfer et al. (2014) found that compared with all-cargo carriers, the combination flighters are less impacted by the economic crisis. Given the imbalances between some incoming and outgoing cargo flows (due to trade imbalances), a potential solution is flying in triangles or using belly capacity (Kupfer et al., 2016). However, the role of airports is minimized in these studies, in which only airline operations were considered. Because airlines at the gateway airport provide both passenger and cargo services, the role of airports in supporting combination flights will be addressed in this paper.

Second, our work is also related to the role of air cargo in airline and airport operations; this area has received less attention in the literature (Mayer, 2016), but it has had more attention recently. Jiang et al. (2003) conducted an analysis of future air cargo demand in China and its implications for system infrastructure. Kupfer et al. (2009) used the bankruptcy-forecasting model to analyze the financial health of full freighters, such as Cargolux. Several other studies identified the role of air cargo in airport operations. Mayer (2016) used a hierarchical cluster analysis to identify eight distinct clusters for airports in terms of their cargo activities. Five out of 114 airports were identified as "Cargo-Dependent Europeans" or "North American Cargo Primaries".⁶ Merkert and Ploix (2014) revealed a significant relationship between international freight volumes, terminal organisation and freighter operations at airports. There are also few studies (e.g., Schwieterman, 1994; Zhang, 2003; Gardiner et al., 2005; Ohashi et al., 2005; Bowen, 2004; Chao and Yu, 2013) to look at airport competitiveness, in terms of air cargo. Although the importance of airport in air cargo operation has been identified, there is a lack of theoretical models to investigate the interrelations between airport and air cargo operations. However, it is common for airports to compete with each other for passenger and cargo in the same catchment area, but less research looks at the impact of airport competition on the air cargo industry. This paper aims to address this issue in a theoretical model, which is supplemented with numerical simulations. Our work may also shed some lights on demand forecast for airport infrastructure facilities for cargo.

Third, the gateway-hinterland infrastructure competition has also been examined in the literature (e.g., Zhang, 2007; De Borger et al., 2008; Yuen et al., 2008). This strand of literature focuses mainly on capacity investment and the pricing of congestible facilities, which serve only passenger traffic. We extend this literature by considering the interaction between the passenger and cargo markets. To the best of our knowledge, no study provides an explicit analysis of the gateway-hinterland airport competition and explicitly considers the two markets and welfare implications for stakeholders.

3. Coordination and competition between gateway and hinterland airports

It is important to investigate how gateway and hinterland airports interact with each other, and what types of interaction would be socially beneficial. Generally speaking, coordination between the two airports could avoid duplication in facility building and improve the utilization of existing facilities. Thus, coordination (or central planning) could achieve the first-best outcome in terms of

⁶ The five airports are LEJ, LGG, ANC, MEM and SDF. The mean of cargo as a percentage of the total Work Load Unit (WLU) for the two clusters are 87.5% and 86.7%, respectively.

social welfare. Hence, when both gateway and hinterland airports are under the same regional government, coordination between the two airports is more likely.

However, coordination becomes much more difficult when the gateway and hinterland airports belong to different regional governments. Without coordination, a gateway government may initiate various competitive strategies, such as capacity investment. The anti-competitive strategy taken by a gateway airport could effectively hinder the entry of the hinterland airport. Without an efficient redistributive system, barriers to coordination would depend largely on the hinterland airport's impacts on different stakeholders. Therefore, it is also important to examine the impact on different stakeholders in markets with different characteristics.

The competition and coordination between gateway and hinterland airports can be formulated as follows. If the gateway and hinterland airports are owned by the same government (i.e., the central planning case), the central government may take stakeholders' interests into consideration during its decision-making process. For example, it may choose certain policy variables to maximize its regional benefits, i.e.,

$$\text{Max} SW = SW\left(CS, SB, \pi^G, \pi^H, TR\right), \quad (1)$$

where SW is a function of passengers' benefits (CS), shippers' benefits (SB), airlines' profits at the gateway and the hinterland airports (π^G and π^H , respectively), and total profits of the gateway and hinterland airports (TR).⁷ When we conduct the cost and benefit analysis for the introduction of the hinterland, TR^H could be interpreted as the profit that has already taken the fixed investment cost into account.⁸ Additionally, we consider only the benefits received by passengers and shippers for air services; in practice, the aviation industry also brings many indirect benefits to other sectors in an economy, including trade services and tourism.⁹

To maximize the regional benefits, several policy variables should be considered. First, the government could use airport charges (ρ_G , ρ_X and ρ_H for cargo and passengers at the gateway airport, and cargo at the hinterland, respectively) to affect the behaviors of airport users, including airlines, passengers and shippers. In particular, the airport charges may be used as a tool to allocate cargo demands between the gateway and hinterland airports.¹⁰

In addition to airport charges, land transportation connecting to the two airports is an important policy issue in the inter-modal transportation system. Thus, in the analysis, we also first consider the land transportation costs to the two airports (i.e., t) as a choice variable for the government. The government could lower transportation costs by several means, including investing in road capacity and/or lowering road tolls. Shippers may also incur additional costs when transporting their products to the gateway airport due to extra costs and delays in crossing borders, poor connectivity among transportation systems in the gateway and the

hinterland, etc.¹¹ In our model, the additional transportation costs to the gateway airport are captured by the parameter γ_G . The government may lower the additional costs (i.e., γ_G) by, for example, improving the customs efficiency and investing in transportation facilities that connect the gateway and the hinterland.¹²

If the gateway and hinterland airports are owned by two separate governments, each government will take only its own interest into account when making policy decisions (i.e., the airport competition case). For example, the gateway government will maximize its welfare as follows:

$$\text{Max} SW^G = SW^G\left(CS, SB, \pi^G, TR^G\right), \quad (2)$$

where SW^G is a function of passengers' and shippers' benefits, gateway airlines' profits, and the gateway airport's profit.

Similarly, the hinterland government may consider the following welfare maximization problem:

$$\text{Max} SW^H = SW^H\left(CS, SB, \pi^H, TR^H\right), \quad (3)$$

where SW^H is a function of passengers' and shippers' benefits, hinterland airlines' profits, and the hinterland airport's profit.

In the following, we formulate an analytical model to examine the interaction between the gateway and the hinterland.

3.1. Shippers and passengers

First we consider the shippers' decision and the passengers' choices in the cargo market and passenger market, respectively. To derive the demands for the airports (and airlines), we first specify benefits of shippers who ship their cargos by air.¹³ Specifically, the net benefits of the shipper could depend on the revenue they receive from selling goods overseas, airport choice, airline charges, scheduling flexibility and transportation costs. For example, if a shipper chooses the hinterland airport to ship its goods, its net utility can be written as:

$$U_H = U_H[V, P_H, E_H(f_H), t], \quad (4)$$

where V denotes the revenue from selling the goods to foreign markets; P_H is the cargo fee charged by airlines at the hinterland airport, which will be decided in the second stage of our model; and $E(\cdot)$ captures the monetary value of shippers' benefits due to increasing flight frequency. Thus, $E'_H(f_H) > 0$. In practice, the benefits of more flights may come from two sources (Douglas and Miller, 1974): (i) the time difference between a shipper's desired departure and the closest scheduled departure by the airline is

⁷ The setting of welfare-maximizing airport by choosing airport charges is commonly used in the aviation economics literature (e.g., Pels and Verhoef, 2004; Zhang and Zhang, 2006). In the studies, social welfare is defined similar to that in (1), which is the sum of air service users' benefit, airlines' and airports' profits.

⁸ In practice, the costs of developing a hinterland airport can be substantial. For example, Liege airport in Belgium is the first European airport to have based its strategy primarily on full cargo operation. In 2015, the airport planned an investment of €10 million for the infrastructure expansion.

⁹ It is estimated that the indirect effect of aviation was approximately 4.5% of Hong Kong's GDP in 2003 (Fung et al., 2006).

¹⁰ The role of airport charges in the present model is mainly to affect the demands of passengers and cargos at the gateway and hinterland airports. The revenue collected is considered as the general tax revenue to the government. In practice, the revenue could also be used to improve the service quality at the airport, for example, increasing the capacity to ease congestion (Zhang and Zhang, 2006).

¹¹ For example, shippers and truckers transporting goods from the PRD region to Hong Kong usually incur four to six hour delays at the border crossing, which implies missing cut-off times at the air cargo handling terminal, and dollars lost for the shipper (Strategic Access, 2007). GHK (2004) estimated that the cost of "crossing boundaries" was approximately HK\$1200 per container.

¹² Another important policy variable for airports is the capacity investment. The capacity investment at an airport is usually considered as part of long-term planning, which will not be examined in the present paper. Nevertheless, exploring this topic would be an important extension of the paper.

¹³ For the purpose of analytical simplicity, our analysis does not consider the role of freight forwarders in the analytical model. In reality, it is most often the freight forwarder that decides on the routing of the cargo. In its decision process, the forwarder considers that it may gain additional cost advantages by consolidating shipments from different shippers at a single large airport. This advantage could be captured in $E(\cdot)$, which implies a positive relationship between cargo volume and shippers/forwarders' benefits.

likely to be smaller¹⁴; (ii) the delayed cost due to excess demand for one's preferred flight(s) is likely to be lower. As the hinterland airport only serves cargo, its flight frequency f_H increases in its cargo volume (i.e., q_H). Finally, the shippers' benefit also depends on the transportation costs to the airport (i.e., t).

Similarly, if a shipper chooses the gateway airport to ship its goods, its net utility can be written as:

$$U_G = U_G[V, P_G, E_G(f_G), t, \gamma_G], \quad (5)$$

where P_G is the cargo fee charged by airlines at the gateway airport. Because airlines operating at the gateway airport use combination flights to serve both passengers and cargo, its flight frequency, f_G , increases with both passenger (i.e., q_X) and cargo volume (i.e., q_G). Accordingly, an increase in passengers or cargo will increase the number of flights at the gateway airport, thereby increasing shippers' net benefits. Given this, demand complementarity between cargo and passengers exists.

Using equations (4) and (5), total cargo demands faced by airlines at the gateway and hinterland airports can be derived as follows:

$$\begin{aligned} q_H &= q_H[V, P_H, P_G, E_H(f_H), E_G(f_G), t, \gamma_G], \\ q_G &= q_G[V, P_H, P_G, E_H(f_H), E_G(f_G), t, \gamma_G]. \end{aligned} \quad (6)$$

Given equation (6), the inverse demand function can be derived as follows:

$$\begin{aligned} P_H &= P_H[V, q_H, q_G, E_H(f_H), E_G(f_G), t, \gamma_G], \\ P_G &= P_G[V, q_H, q_G, E_H(f_H), E_G(f_G), t, \gamma_G]. \end{aligned} \quad (7)$$

Now, we turn to the passenger market. Because only the gateway airport serves the passenger market, the decision for passengers is whether to use the gateway airport. Specifically, we assume that if the consumer chooses to travel, he/she derives a net utility:

$$U_X = U_X[V_X, P_X, E_X(f_G)], \quad (8)$$

where V_X denotes a monetary value of gross utility for passengers choosing travel¹⁵; P_X is the air fare charged by airlines at the gateway, which will be decided in the second stage of our model; $E_X(\cdot)$ captures the passengers' benefits due to the increasing flight frequency. Thus, $E'_X(f_G) > 0$. Passengers' benefits due to increasing flight frequency are indeed well-documented in the empirical literature (e.g., Skinner, 1976; Windle and Dresner, 1995; Pels et al., 2001). Using equation (8), the passenger demand for the airlines at the gateway airport can be obtained as follows:

$$q_X = q_X[V_X, P_X, E_X(f_G)]. \quad (9)$$

From equation (9), the inverse demand can be obtained as follows:

$$P_X = P_X[V_X, q_X, E_X(f_G)]. \quad (10)$$

3.2. Airlines

We examine the interaction between airlines at the gateway and

¹⁴ To capture this factor, Brueckner and Zhang (2001) considered a model in which consumers' desired arrival times are uniformly distributed over a circle representing a 24-h clock, and the airlines space their arrival times equally around the circle.

¹⁵ V_X may also capture the passengers' disutility of travel time/transportation time cost.

hinterland airports, given the demands derived above. In particular, gateway airlines serve both passenger and cargo traffic, while hinterland airlines serve only cargo traffic. In this paper, we assume that airline competition in each region is perfectly contestable. This could happen when airlines provide homogenous products in the cargo and passenger markets, in which consumers do not have any preference across airlines. In this case, airlines do not have any market power to set air fares for passengers or cargo. Therefore, unit passenger fares and unit cargo fees are equal to airlines' respective unit operating costs, plus the airport's respective charges for passengers and cargo.¹⁶ Thus, cargo fees at gateway and hinterland airports and air fares can be written as follows:

$$P_G = \rho_G + C_G(q_G, q_X), P_H = \rho_H + C_H(q_H), P_X = \rho_X + C_X(q_G, q_X), \quad (11)$$

where $C_G(q_G, q_X)$ and $C_X(q_X, q_G)$ are the unit costs for the gateway airlines serving cargo and passengers, respectively. We further assume that $\partial C_j / \partial q_j < 0$ and $\partial C_{-j} / \partial q_j < 0$, where $j \in [G, X]$, which captures the economies of density and scope, respectively. It is well documented that the economies of density and scope exist in the airline industry for a number of reasons (e.g., Caves, et al., 1984; Brueckner and Spiller, 1994). For example, airline operations involve a huge amount of fixed investments, including aircraft fleet and infrastructures at airports. Economies of density and scope exist when these fixed costs are spread over more units of outputs. Therefore, cost complementarity exists between passenger and cargo operations. In particular, if there is a strong demand for passenger travel which creates a large amount of belly capacity, the additional cost of providing capacity for cargo will be low. Another interpretation of the cost complementarity is that supported by passenger traffic volume; gateway airports usually have a better network for cargo transportation via combination flights, while cargo transported through hinterland airports often need to be transferred via other gateway airports to reach its final destination. This difference could explain a possible cost advantage for gateway airports/airlines in transporting cargo.

Let $C_H(q_H)$ be the unit cost for the hinterland airline serving cargo. Again, we assume that $\partial C_H / \partial q_H < 0$, which captures the economies of scale.¹⁷ Pricing equations in (11) suggest that the cost savings due to economies of scope and scale will be 100% passed on to the consumers. Notably, the perfectly contestable case, indeed, helps abstract away complexity due to airlines' strategic pricing behaviors. Here, ρ_G , ρ_H , and ρ_X are the per-unit airport charges for cargo at the gateway and hinterland airports and for passengers, respectively.

3.3. Airports

Given the airlines and consumer behaviors discussed above, each airport maximizes its respective welfare.¹⁸ We consider the central planning case and the airport competition case. For the

¹⁶ Here we focus mainly on the role of economies of scope and scale in the cost function of passengers and cargo. Another important issue is about cost allocation between passengers and cargo. There are various methods of the cost allocation, including the "by-product" (revenue offset) methods, the "joint product" (fully allocated costs) methods, and no cost allocation (Morrell, 2016). It is worthwhile to look into this issue for further analysis in the future.

¹⁷ Both the pooled results and carrier-specific results for UPS and FedEx in Lakew (2013) showed that the integrated air cargo industry's cost structure is characterized by increasing returns to size.

¹⁸ One more possible scenario is private airports. In this scenario, the private airport will choose the airport charges to maximize its own interest. In our model, the equilibrium can be characterized by the following first-order conditions.

central planning case, the airport solves the maximization problem in (1) by choosing airport charges.¹⁹ The equilibrium can be characterized by the following first-order conditions:

$$\partial SW/\partial \rho_G = 0; \quad \partial SW/\partial \rho_X = 0; \quad \partial SW/\partial \rho_H = 0 \quad (12)$$

By solving the equations in (12), the optimal airport charges can be obtained.

For the airport competition case, each airport (i.e., the gateway and hinterland airports) maximizes its own welfare. In particular, the gateway airport chooses airport charges for cargo and passengers to solve the maximization problem in (2). We then obtain the following first-order conditions:

$$\partial SW^G/\partial \rho_G = 0; \quad \partial SW^G/\partial \rho_X = 0. \quad (13)$$

Similarly, the hinterland airport chooses airport charges for cargos to solve the maximization problem in (3), and we obtain the following first-order condition:

$$\partial SW^H/\partial \rho_H = 0. \quad (14)$$

4. Analytical results with specific functional forms

We further use specific functional forms to examine the market equilibrium. The choices of specific functional forms satisfy the assumptions we made in Section 3: $F(\cdot) > 0$ captures the monetary value of shippers' and passengers' benefits due to increasing flight frequency; $\partial C_j/\partial q_j < 0$ and $\partial C_{-j}/\partial q_j < 0$, where $j \in [G, X]$, capture the economies of density and scope, respectively. First, to investigate the shippers' demand, we assume that the representative shipper will incur the "generalized cost" or "full price" if he/she chooses to use the hinterland and gateway airports, respectively:

$$p_H = P_H - a_H q_H + t, \quad p_G = P_G - a_G (q_G + r q_X) + \gamma_G t, \quad (15)$$

where P_j is air cargo fee charged by airline j , t is the transportation costs at the hinterland, and $\gamma_G > 1$, which captures the fact that transportation costs to the gateway are usually higher than those to the hinterland. The flight frequency at the gateway airport is defined as $f_G = r_G + r q_X$, where r captures the ratio of cargo and passengers (in terms of weight, for example) per flight²⁰; a_G and a_H in (15) capture the increase in the monetary value of shippers' benefits due to the increasing flight frequency at the hinterland and gateway airports, respectively; e.g., less schedule delay cost. Thus, $a_j > 0$. In particular, a_H and a_G capture the magnitude of shippers' benefits due to the frequency increase at the hinterland and gateway airports, respectively.

The representative shipper solves the following constrained maximization problem:

¹⁹ It is common in airport economics to consider how airport charges could improve social welfare from different perspectives, including airport congestion (e.g., Pels and Verhoef, 2004), airline network choice (e.g., Oum et al., 1996), and aviation-related environmental cost (e.g., Nero and Black, 1998). In practice, airport charges also reflect the operating costs and are often regulated. On the other hand, the airports or governments could also consider other tools, including lowering transportation costs and improvements in connectivity between the gateway and the hinterland, to achieve the social optimum. They will be further investigated in the numerical simulation.

²⁰ The implicit assumption for the frequency equation is that both passengers and cargo will affect the frequency. If there is overcapacity of belly cargo, then the marginal increase in cargo will not affect the frequency. The frequency equation will be reduced to $f_G = r q_X$.

$$U(q_G, q_H) = \alpha_H q_H + \alpha_G q_G - \frac{1}{2} (\beta_H q_H^2 + \beta_G q_G^2 + 2\alpha_H q_H q_G) - p_H q_H - p_G q_G.$$

By solving the shipper's maximization problem, we obtain the following inverse demand functions:

$$p_H = \alpha_H - \beta_H q_H - \alpha q_G, \quad p_G = \alpha_G - \beta_G q_G - \alpha q_H. \quad (16)$$

Equating (15) and (16), we have:

$$P_H = \alpha_H - \beta_H q_H - \alpha q_G - \alpha_H q_H - t, \quad (17)$$

$$P_G = \alpha_G - \beta_G q_G - \alpha q_H - \alpha_G (q_G + r q_X) - \gamma_G t. \quad (18)$$

Similarly, we consider that the representative consumer faces the following full-price function:

$$p_X = P_X - a_X (q_G + r q_X), \quad (19)$$

where P_X is the passengers' air fare and a_X captures the magnitude of passengers' benefits due to frequency increase.

Then, he/she solves the following constrained maximization problem:

$$U(q_X) = \alpha_X q_X - \frac{1}{2} \beta_X q_X^2 - p_X q_X.$$

We then obtain the inverse linear demand function:

$$p_X = \alpha_X - \beta_X q_X, \quad (20)$$

Equating (19) and (20), we have:

$$P_X = \alpha_X - \beta_X q_X + a_X (q_G + r q_X). \quad (21)$$

For the airlines, we assume that the unit cost functions are $C_H(f_H) = d_H - c_H q_H$, $C_G(q_G, q_X) = d_G - c_G q_G - c_X q_X$ and $C_X(q_G, q_X) = d_X - w_X q_X - w_G q_G$ where $c_H, c_G, w_X > 0$ capture the magnitudes of scale economies for cargo operations at the hinterland and gateway airports and for passengers, respectively. $c_X, w_G > 0$, which capture the magnitudes of scope economies for cargo and passenger operations at the gateway airports. c_X, q_X could also be interpreted as follows: the strong demand for air passengers may create a large amount of belly capacity, which is potentially sold at lower costs if the capacity would otherwise remain unused.

By differentiating the first-order conditions with respect to airport charges, we obtain the following comparative statics (see the proof in the Appendix):

$$\frac{\partial q_G}{\partial \rho_H} > 0, \quad \frac{\partial q_X}{\partial \rho_H} > 0, \quad \frac{\partial q_H}{\partial \rho_H} < 0, \quad (22)$$

$$\frac{\partial q_G}{\partial \rho_G} < 0, \quad \frac{\partial q_X}{\partial \rho_G} < 0, \quad \frac{\partial q_H}{\partial \rho_G} > 0, \quad (23)$$

$$\frac{\partial q_G}{\partial \rho_X} < 0, \quad \frac{\partial q_X}{\partial \rho_X} < 0, \quad \frac{\partial q_H}{\partial \rho_X} > 0. \quad (24)$$

Equations (22)–(24) suggest that an increase in an airport's charges decreases its air cargo output but increases the output of the other airport. Furthermore, an increase in the gateway airport charges, imposed on either passengers or cargo, decreases passenger output. However, an increase in the cargo airport charge at

the hinterland airport increases passenger output at the gateway airport.²¹ It is rather obvious that the increase in airport charges in one particular market will reduce the traffic of that market (i.e., the direct effect). However, it is important for governments and airports to pay attention to the indirect effect of airport charges on other markets: 1) the impact of airport charges on gateway passengers (cargo, respectively) on the gateway air cargo (passengers, respectively) due to the complementarity between those two markets; 2) the impact of airport charges for gateway passengers on the cargo at the hinterland; and 3) the impact of airport charge for hinterland cargo on gateway passengers. These results are similar to that in [Basso and Zhang \(2007\)](#), in which they found that an airport charges increase will lead to higher demand in its competing airport. But the paper only considered a single market – passenger market – but not the interaction between passenger and cargo markets.

5. Application to competition/coordination between the Hong Kong and Shenzhen airports

One of the examples of the phenomenon previously discussed herein is the competition between the Hong Kong and Shenzhen airports. In recent decades, the economies of the PRD region grew rapidly; the gross domestic product (GDP) of the region in 2014 was US\$931 billion (9.1% of China's GDP).²² In recent years, due to rising labor costs in the region and policy changes in China, the region began shifting its focus to high-valued added industries, such as the hi-tech industry. This change leads to huge demands in air cargo service. The airfreight traffic of the PRD region increased to 2.5 billion tons in 2014,²³ and it is estimated that the market of air cargo in the region will grow to 18 million tons of cargo in 2030 ([HKIA, 2011](#); [Hong Kong International Airport Website](#)).

Currently, five airports, Hong Kong, Shenzhen, Guangzhou, Zhuhai, and Macau, serve the air cargo market in the PRD region. Among them, the competition between Hong Kong and Shenzhen is particularly interesting. The distance between the two airports is approximately 30 km. While Hong Kong serves as a gateway airport, Shenzhen airport positions itself as an international cargo airport in the hinterland.²⁴ In particular, there are two major differences between the two airports. First, the Shenzhen airport is closer to the cargo source; thus, shippers may incur lower ground transportation costs from the manufacturing site to the airport. However, air cargo to Hong Kong is required to go through customs between Mainland China and Hong Kong. This process leads to additional costs compared to the costs of using the Shenzhen airport.

Second, although it seems that it is more costly to ship air cargo from Hong Kong than from Shenzhen, we observed that the cargo volume at the Shenzhen airport is only 15% of that of the Hong Kong airport - this observation could be related to the difference in operation costs between airlines at the two airports. The Hong

Kong airport maintains a huge operation in passenger traffic, where the passenger-cargo mix is approximately 70%–30%, respectively. Airlines in Hong Kong largely use combination flights that serve both passengers and cargo. Such operations may lead to cost and demand complementarities between passengers and cargo. However, the Shenzhen airport serves the cargo market by providing dedicated cargo flights. For example, UPS uses the airport as its cargo hub in Asia. Because of the separation of passenger and cargo operations at the airport, there are almost no complementarities between passenger and cargo flights.

In the numerical analysis, we use real-life data to estimate the parameters in our proposed model. In particular, most parameters of our analytical model are not available in the literature. The estimation of the model parameters is carried out by a calibration procedure, in which the parameters have been adjusting until model outputs (e.g., the cargo share between Hong Kong and Shenzhen, price elasticities, and the share of land transportation costs in total) match real-world observations. For the demand function, the parameters are chosen such that the price elasticities are within the range estimated in the literature. For the passenger market, the (absolute) price elasticity ranges between 0.4 and 2.0 ('air travel demand', [IATA, 2008](#)), depending on the flight distance and the regions considered. The price elasticity in the cargo market is difficult to generalize because it is very sensitive to specific market situations and to the degree of aggregation of the data, and the range of the estimates is large (from –5.6 to –0.21) in various studies (e.g., [Wang et al., 1981](#); [Oum et al., 1990](#); [Chi and Baek, 2012](#); [Lo et al., 2015](#); [Wan and Zhang, 2016](#)). Accordingly, we choose the parameter, α , as well as α_C and α_H , such that the market share of cargo between the Hong Kong and Shenzhen airports is 85%: 15% (based on the 2009 figures). The value of α_X is chosen such that the revenue ratio between cargo and passengers is 30%:70% (based on the figures from Cathay Pacific operating results of 2009).

Based on the 747–400 configuration, assuming an average passenger weight equal to 100 kg and the maximum payload equal to 112,639 kg, we set r to 1.15. The airport choice literature estimated the positive impact of flight freight frequency of passengers. For example, the estimate of the willingness to pay for one additional flight at a base frequency of 5 flights in the San Francisco Bay area is US\$8.25 ([Hess and Polak, 2005](#)). Notably, the estimates depend highly on passenger income, the purpose of the trip, flight distance, etc. For air cargo markets, such estimates have not been reported in the literature. Thus, in the numerical analysis, we will conduct sensitivity analysis to investigate how the estimates affect our results.

Many studies have been conducted to investigate the cost structure of the airline industry, particularly looking at the existence of economies of scale (density) and scope (e.g., [Caves et al., 1984](#); [Gillen et al., 1990](#); [Oum and Zhang, 1991](#)). For example, [Caves et al. \(1984\)](#) found that a 1% increase in output leads to an increase in total cost of only 0.8%. However, a variety of cost functions have been proposed, and their estimates could be significantly different if different specifications and variables are chosen for the total cost function. In this study, we will conduct sensitivity analysis to determine how the magnitudes of the economies of scale and scope affect our results. The airport charge per passenger is approximately 3% of the air fare at the Hong Kong airport (based on the information from the Hong Kong Airport Authority). Other costs, including transportation costs to the airports (t) and airport charges on air freight, etc., are based on the survey results ([GHK, 2004](#)).

The estimates for our benchmark case are given in [Table 1](#).

In the following discussion, we consider social welfare implications. Here, we define the respective social welfare at the gateway and hinterland airports as follows:

²¹ The comparative static results show only the relationship between variables, while the magnitude of the relationships depends on specific markets and regions considered. For example, belly cargo is often seen as a by-product of the passenger business in some regions, such as Europe. Thus the (negative) impact of cargo charges on passenger demand may not be significant at some gateway airports.

²² Source: Guangdong Statistical Yearbook 2015.

²³ Source: Hong Kong Trade Development Council, website.

²⁴ It is reported that in 2015, the Shenzhen airport received 1.66 million passengers from 16 international routes, accounting for only 4% of the total (China Daily, April 13, 2016). Thus, the capacity of the combination flight for international cargo is limited. Instead, there are 12 international airfreight-dedicated airlines operating at the Shenzhen airport. For example, Lufthansa Cargo operates direct Shenzhen-Frankfurt flight for air cargo, while Lufthansa does not have any non-stop flights between the two cities for passengers.

Table 1
Parameterization in the benchmark case.

Demand functions			
α_G	1800	β_G	0.8
α_H	325	β_H	0.8
α_X	2900	β_X	1
α	0.01		
Transportation costs to airports			
t	10	γ_G	3
Frequency benefit functions			
r	1.15	a_G	0.01
a_H	0.01	a_X	0.05
Cost functions			
b_G	10	b_H	2
b_X	10	ρ_G	46
c_G	0.005	ρ_H	341
c_H	0.005	ρ_X	27
c_X	0.0005	w_G	0.0005
w_X	0.005		

$$SW^G = CS + SB + \pi^G + TR^G$$

$$SW^H = CS + SB + \pi^H + TR^H$$

where SW^G is the sum of the passengers' benefits (CS), shippers' benefits (SB), gateway airlines' profits (π^G), and gateway airport profit (TR^G). The gateway airport profit are the total revenue from passengers and cargos (i.e., $TR^G = \rho_X q_X + \rho_G q_G$).²⁵ SW^H is the sum of CS, SB, hinterland airlines' profits (π^H), and hinterland airport profit (TR^H). The hinterland airport profit is from cargos (i.e., $TR^H = \rho_H q_H$). We further examine the social welfare for the whole region, which is defined as follows:

$$SW = CS + SB + \pi^G + \pi^H + TR^G + TR^H.$$

Table 2 shows the market outcomes of the benchmark case.

5.1. Sensitivity analysis

We first look at a_G , the parameter capturing the positive impact of increasing flight frequency at the gateway airport on shippers' benefits. We find that the increase in a_G will lead to an increase in cargo output at the gateway airport because shippers will enjoy more benefits due to frequency increase at the airport (Ohashi et al., 2005). The increase in cargo at the gateway airport also increases the flight frequency at the gateway airport, which leads to both cost savings for the gateway airlines (i.e., economies of scope) and increased passenger benefits due to more flights (Douglas and Miller, 1974). Hence, more passengers will fly.

For the impact of social welfare, an increase in a_G will lead to an improvement in social welfare in both the gateway and hinterland areas, which include the sum of consumer surplus, shippers' benefits, airlines' profit and airport profit at the two airports. In particular, passengers' and shippers' benefits will increase. However, the airport profit and airlines' profits will increase at the gateway airport, while those at the hinterland airport will decrease. Similar results are found for a_X (capturing the positive impact on passengers' utility due to increasing frequency), c_G (capturing the magnitude of scale economies in the cargo operation of the

²⁵ In the analytical model, we focus mainly on the dynamics in the airlines, passenger and air cargo markets. For simplicity, we assume that the operating cost of airport is zero, thus the airport revenue equal to its profit. This assumption will not affect our major conclusions. Someone could consider that the operating cost has been reflected in parameter b in the airline cost function. In the social-welfare maximizing case, airports consider both airport and users' benefits. The choice of airport charges will not be affected by who absorbs the costs.

Table 2
Market equilibrium for the benchmark case.

	Simulated figures
Equilibrium output	
Cargo volume at the gateway (q_G)	971.7
Cargo volume at the hinterland (q_H)	176.0
Passenger volume (q_X)	540.0
Social welfare	
Total welfare (SW)	4.43×10^6
Regional welfare at the gateway (SW_G)	4.14×10^6
Regional welfare at the hinterland (SW_H)	1.18×10^6
Airport profit at the gateway (TR_G)	4.02×10^5
Airport profit at the hinterland (TR_H)	4751.4
Profit of airlines at the gateway (π_G)	2.88×10^6
Profit of airlines at the hinterland (π_H)	24,309.6
Shippers' benefits (SB)	12,702.2
Passengers' benefits (CS)	1.11×10^6

gateway airlines), c_X (capturing the magnitude of scope economies in cargo operations of the gateway airlines), w_X (capturing the magnitude of scale economies in the passenger operations of gateway airlines), and w_G (capturing the magnitude of scope economies in passenger operations of the gateway airlines).

However, an increase in a_H (capturing the positive impact on shippers' benefits due to increasing frequency at the hinterland airport) will lead to an increase in cargo output at the hinterland airport and a decrease in cargo output at the gateway airport. The decrease in cargo at the gateway airport also decreases the flight frequency at the gateway airport, which leads to both increasing costs for the gateway airlines (due to scale and scope economies, see Gillen et al., 1990; Antoniou, 1991) and decreasing passengers' benefits due to fewer flights. Hence, fewer passengers will fly. The welfare implications are similar to those for a_G . The exception is that the airport and airlines' profits will increase at the hinterland airport, while those at the gateway airport will decrease. Similar results are found for c_H (capturing the magnitude of scale economies in hinterland airlines' cargo operations).

When the transportation cost (i.e., t) increases, cargo output at the gateway and the hinterland airports will decrease. Given the decreasing flight frequency at the gateway airport due to less cargo, the airlines' costs of serving passenger will increase (economies of scope), and passengers' benefits will decrease. Thus, fewer passengers will fly. The increase in transportation costs will lead to lower shippers' and passengers' benefits, airlines' and airports' profits, and, thereby, social welfare at the gateway and hinterland airports.

6. Discussions

6.1. Is the introduction of a hinterland airport beneficial to the society and other stakeholders?

In this section, we compare two scenarios: i) the cargo market when served by the gateway airport only, and ii) the cargo market when served by both the gateway and the hinterland airports. In particular, we examine the changes in market outputs (i.e., q_G and q_X), social welfare in the two regions, airlines' profits, and shippers' and passengers' benefits.

Table 3 shows the comparison between scenarios (i) and (ii) in our benchmark case (column showing 0%). First, we find that the cargo and passenger volumes at the gateway airport decrease when we introduce the hinterland airport. Additionally, the social welfare at the gateway airport, its respective airport profit, and the airlines' profits and passengers' benefits will all decrease, while the social welfare at the hinterland airport and the shippers' benefits will

Table 3
The welfare implication of the introduction of the hinterland airport.

		% change in a_G (shippers' benefits due to higher frequency at the gateway)										
		-100%	-80%	-60%	-40%	-20%	0%	20%	40%	60%	80%	100%
% Change from single to dual airport	q_G	-0.117%	-0.117%	-0.116%	-0.116%	-0.116%	-0.115%	-0.115%	-0.115%	-0.115%	-0.115%	-0.114%
	q_X	-0.002%	-0.002%	-0.002%	-0.002%	-0.003%	-0.003%	-0.003%	-0.003%	-0.003%	-0.003%	-0.003%
	SW	0.623%	0.620%	0.617%	0.614%	0.612%	0.609%	0.606%	0.603%	0.600%	0.597%	0.594%
	SW_G	-0.060%	-0.046%	-0.032%	-0.045%	-0.047%	-0.046%	-0.047%	-0.048%	-0.049%	-0.051%	-0.051%
	SW_H	2.586%	2.573%	2.560%	2.546%	2.531%	2.520%	2.511%	2.502%	2.481%	2.467%	2.453%
	TR_G	-0.060%	-0.093%	-0.094%	-0.094%	-0.096%	-0.096%	-0.095%	-0.096%	-0.095%	-0.095%	-0.095%
	π_G	-0.059%	-0.059%	-0.059%	-0.059%	-0.059%	-0.061%	-0.059%	-0.062%	-0.060%	-0.060%	-0.060%
	SB	0.8700%	0.798%	0.640%	0.499%	0.3032%	0.250%	0.143%	0.045%	-0.045%	-0.128%	-0.204%
	CS	-0.005%	-0.005%	-0.005%	-0.005%	-0.005%	-0.006%	-0.006%	-0.006%	-0.006%	-0.006%	-0.006%

Note: If the number is negative, the equilibrium value in the case without the hinterland airport is larger than that in the case with the hinterland airport.

increase. Overall, the social welfare of the economy will increase by 0.61%, when the hinterland airport is introduced.²⁶

We also examine the effect on the benefits of introducing the hinterland airport with respect to different sets of parameter values. Table 3 shows the results for a_G , which captures the magnitude of shippers' benefits due to higher frequency at the gateway. It is interesting to note that shippers could be better or worse off, depending on the magnitudes of a_G . When a_G is small, shippers will be better off if the hinterland airport is introduced. Intuitively, if there is no hinterland airport, more shippers will use the gateway airport, implying higher flight frequency and greater benefits. When a_G is large, such benefits can outweigh the benefits of having the hinterland airport, including lower transportation costs, etc.

In addition, with respect to shippers' benefits, we find that the introduction of the hinterland airport means that the gateway airport will be worse off while the hinterland airport will be better off. Taken together, the aggregate welfare of the gateway and the hinterland airports will improve. Moreover, airlines at the gateway will be worse off due to the competition from airlines at the hinterland airport. Finally, passengers will be worse off due to lower frequency to the gateway after the introduction of the hinterland airport.

We also conduct similar sensitivity analysis on other parameters. In summary, we find that after the introduction of the hinterland cargo airport, shippers tend to be better off when higher frequency at the hinterland airport contributes significantly to shippers' benefits, when scale economies of the cargo operation at the hinterland airport are important, or when the transportation costs and the gateway airport charges are high. However, the shippers will be worse off when passengers' benefits increase due to a higher flight frequency when scale economies of cargo and passenger operations at the gateway and scope economies between cargo and passengers are important, or when the hinterland airport charge is high. The implications for the aggregate welfare, the gateway and hinterland welfares and the welfares of the airlines and passengers are similar to those shown in Table 3.

6.2. Is regional coordination better than competition?

In practice, there are many types of coordination between the

gateway and the hinterland airports, including information exchange, capacity sharing, cooperative pricing at airports, improving connectivity between the two regions and cross-shareholding between the airports, etc. In this study, we focus on only two types: connectivity between the gateway and the hinterland airports and airport charges in the two regions.

In a gateway-hinterland transport system, it is crucial to have good connectivity between the gateway and the hinterland because coordination between the two areas is necessary for improving the connectivity.²⁷ Comparing coordination and competition between gateway and hinterland airports, we also investigate how the improvement of gateway and hinterland connectivity will affect market equilibrium and stakeholders' benefits. In our model, a smaller γ_G implies better connectivity to the gateway airport.

Tables 4 and 5 show the impact of connectivity on cargo and passenger volumes and social welfare, respectively. We find that an increase in γ_G (poor connectivity between the gateway and hinterland) will lead to a decrease in gateway cargo output and total cargo output, while hinterland cargo output will increase. Given a decrease in cargo demand at the gateway airport, fewer passengers will fly. Social welfares at the gateway and the hinterland airports, shippers' and passengers' benefits, and airport and airline profits at the gateway airport will all decrease. However, airport and airline profits at the hinterland airport will increase.

We also examine the welfare scenarios as airport charges change after coordination between the two regions occurs. We find that, for example, if gateway airport charges on cargo and passengers and hinterland airport charges on cargo are all decreased by 10%, then the passenger volume will increase 0.21%. At the same time, cargo volumes at the gateway and the hinterland airports will increase 2.25% and 0.90%, respectively. The results also suggest that when the gateway and hinterland airport charges are decreased by the same amount, the percent of the increase at the gateway airport will be higher than that at the hinterland airport. We also explore the cases where i) only the gateway airport reduces its charges, and ii) only airport charges on cargo at the gateway and hinterland airports are reduced. In short, we find that an increase in an airport's charges decreases its air cargo output but increases the output of the other airport. Additionally, an increase in the gateway airport charges imposed on both passengers and cargo decreases passenger output. However, an increase in the cargo airport charge at the hinterland increases passenger output at the gateway. These results are consistent with our analytical results in Section 4.

We further examine how the decreases in airport charges affect

²⁶ It should be noted that the analysis does not take into account the construction cost of the hinterland airport. As mentioned in earlier footnote,⁶ the cost may be substantial and a heavy financial burden on the airport and/or society. The current model aims at providing an analytical framework to look at the market dynamics with and without the hinterland airport. In a (more complete) cost and benefit analysis (CBA) evaluating the investment project of a hinterland airport, it is important to also take into account the construction costs and other possible costs, including environmental costs.

²⁷ As a case in point, the Hong Kong-Zhuhai-Macau Bridge, which connects Hong Kong and the hinterland at the west side of the PRD, has been proposed since the early 1980s. However, there was almost no progress, until the central government took proactive steps to balance the interests among local governments in 2007.

Table 4
Impact of γ_G on cargo and passenger volumes.

		% change in γ_G									
		-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%	-90%	-100%
% Change in	q_G	0.099%	0.197%	0.296%	0.395%	0.493%	0.592%	0.691%	0.789%	0.888%	0.987%
	q_H	-0.003%	-0.007%	-0.010%	-0.014%	-0.017%	-0.021%	-0.024%	-0.028%	-0.031%	-0.035%
	q_X	0.002%	0.004%	0.007%	0.009%	0.011%	0.014%	0.016%	0.018%	0.020%	0.023%

Table 5
Impact of γ_G on social welfare.

		% change in γ_G									
		-10%	-20%	-30%	-40%	-50%	-60%	-70%	-80%	-90%	-100%
% change in	SW_G	0.051%	0.102%	0.160%	0.203%	0.254%	0.314%	0.356%	0.408%	0.459%	0.510%
	SW_H	0.039%	0.078%	0.117%	0.157%	0.196%	0.236%	0.275%	0.315%	0.354%	0.394%
	TR_G	0.082%	0.163%	0.245%	0.327%	0.408%	0.490%	0.572%	0.654%	0.735%	0.817%
	TR_H	-0.003%	-0.007%	-0.010%	-0.014%	-0.017%	-0.021%	-0.024%	-0.028%	-0.031%	-0.035%
	π_G	0.051%	0.101%	0.152%	0.203%	0.254%	0.305%	0.356%	0.407%	0.458%	0.509%
	π_H	-0.007%	-0.014%	-0.021%	-0.028%	-0.035%	-0.042%	-0.049%	-0.056%	-0.062%	-0.069%
	SB	0.965%	1.932%	2.900%	3.870%	4.842%	5.816%	6.792%	7.769%	8.748%	9.728%
	CS	0.005%	0.009%	0.014%	0.019%	0.024%	0.029%	0.033%	0.038%	0.043%	0.048%

the social welfare in both the gateway and the hinterland, and how it affects other stakeholders. First, we find that it is beneficial to both the gateway and the hinterland airports if airport charges are decreased. Particularly, the hinterland airport will gain more than the gateway airport. However, the profit for the airports will decrease when airport charges are decreased. Finally, all airport users, including airlines, shippers and passengers, are better off when airport charges are reduced. Among them, shippers will have the largest gain in terms of the percentage of increase in benefits. We also consider the impact of the change in charges at the gateway and hinterland airports.

7. Concluding remarks

In this paper, we provided an analytical framework to capture the competition (and cooperation) between the gateway and hinterland airports. This paper made contributions to existing literature in the following areas. First, comparing with the studies investigating combination flights (e.g., Zhang and Zhang, 2002b; Slager and Kapteijns, 2004; Zhang et al., 2004, 2007; Sandhu and Klabjan, 2006; Tang et al., 2008; Wong et al., 2009), we further looked at the roles of airports in the analysis. Second, the paper shed lights on the literature related to the role of air cargo operation in airports, by considering airport competition in the same catchment area for air cargo. Finally, the paper considered both passenger and cargo in our theoretical model and numerical simulation, which was not explored in studies using airport-airline vertical structure model (e.g., Zhang, 2007; De Borger et al., 2008; Yuen et al., 2008).

In this paper, we first investigated how the airport charges at the gateway and hinterland airports affect the equilibrium output in the passenger and cargo markets. We found that while an increase in the charges of an airport decreases its air cargo output, it increases the output of the other airport. Additionally, an increase in the gateway airport charges imposed on either passengers or cargo decreases passenger output. However, an increase in the cargo airport charge at the hinterland airport increases passenger output at the gateway airport.

We further investigated an important question for policy making. Is it beneficial to society and to all stakeholders to introduce a cargo airport in the hinterland? We considered the PRD region in China as an example, and used the data of the region to conduct a

numerical analysis. For the analysis, we found that the introduction of the hinterland airport is likely to lead to an improvement in the aggregate welfare of the gateway and the hinterland. We also found that after the introduction of a hinterland cargo airport, shippers are likely to benefit when shippers' benefits at the hinterland is more sensitive to flight frequency, scale economies of the cargo operations at the hinterland are important, and the transportation costs and the gateway airport charges are high. Moreover, the shippers could suffer if the demand complementarity between passengers and cargo is high, scale economies of cargo and passenger operations at the gateway and scope economies between cargo and passenger are important, and the hinterland airport charge is high. Our numerical results not only further illustrate/elaborate our analytical model, but also contribute to managerial and policy insights based on a case study of two important cargo airports, with Hong Kong being No. 1 air cargo airport in the world. For example, based on our results, it may be beneficial for the region to develop/transform the Shenzhen airport into an international cargo airport, given certain market characteristics mentioned above.

Finally, in the numerical analysis, we considered the implications of the coordination between the gateway and hinterland airports. In particular, we investigated the impact of improvement in connectivity between the two regions and the change in airport charges due to potential coordination. We found that if the connectivity between the gateway and hinterland airports improves, there will be an increase in the gateway cargo output and the total cargo output, while the hinterland cargo output will decrease. In addition, the social welfares at the gateway and the hinterland, the shippers' and passengers' benefits, and the airport and airline profits at the gateway airport will increase. However, airport and airline profits at the hinterland airport will decrease. The numerical results highlight the importance of Hong Kong and Shenzhen working together, for example, improving the connectivity between the two cities. However, having an efficient redistributive mechanism to encourage the cooperation between the two cities are crucial to achieve the social optimum, as some stakeholders will be worse off if the connectivity is improved.

The paper has also raised a number of other issues and avenues for future research. First, in social welfare analysis of the introduction of a hinterland airport, we did not explicitly model the investment cost of building the new airport, or the costs of

transforming some secondary passenger airports in the hinterland into cargo-dedicated airports. It is interesting to see whether the costs could be justified by the benefits brought from such an airport identified in the current study. Second, to make the analytical model tractable, several simplifications and assumptions have been made in the analysis. For example, the current study looks only at the competition and cooperation of two airports, namely, the gateway and hinterland airports. In practice, there might be more than one gateway airport in the catchment area.²⁸ It is worthwhile to note how the results in the current study will be affected if there exists another gateway airport in the area. In this paper, we also assume that airline competition in each region is perfectly contestable. Further studies could consider the product differentiation model, in which passengers, shippers and forwarders may have brand preference in their airline choice.

Acknowledgement

We would like to thank the editor and two anonymous referees for their constructive comments, which have improved the paper significantly.

Appendix

First-order condition for the airline maximization problem:

$$\begin{aligned}\pi_G^G(q_X, q_Y, q_G; \rho_G) &= 0; \\ \pi_X^G(q_X, q_Y, q_G; \rho_X) &= 0; \\ \pi_H^H(q_X, q_Y, q_G; \rho_H) &= 0.\end{aligned}$$

Comparative statics:

$$\begin{pmatrix} \pi_{GG}^G & \pi_{GX}^G & \pi_{GH}^G \\ \pi_{XG}^G & \pi_{XX}^G & \pi_{XH}^G \\ \pi_{HG}^G & \pi_{HX}^G & \pi_{HH}^G \end{pmatrix} \begin{pmatrix} \partial q_G / \partial \rho_H \\ \partial q_X / \partial \rho_H \\ \partial q_H / \partial \rho_H \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\begin{aligned}\frac{\partial q_H}{\partial \rho_H} &= \frac{1}{\Delta_1} (\pi_{GG}^G \pi_{XX}^G \\ &\quad - \pi_{GX}^G \pi_{XG}^G) < 0 \quad (\text{by second - order condition})\end{aligned}$$

where $\Delta_1 < 0$ (stability condition).

$$\begin{aligned}\frac{\partial q_G}{\partial \rho_H} &= \frac{1}{\Delta_1} (\pi_{GX}^G \pi_{XH}^G - \pi_{XX}^G \pi_{GH}^G) = \frac{1}{\Delta_1} \pi_{XX}^G \pi_{GH}^G > 0 \quad (\text{where } \pi_{XH}^G \\ &= 0)\end{aligned}$$

$$\begin{aligned}\frac{\partial q_X}{\partial \rho_H} &= \frac{1}{\Delta_1} (\pi_{GG}^G \pi_{XH}^G - \pi_{XG}^G \pi_{GH}^G) = \frac{1}{\Delta_1} \pi_{XG}^G \pi_{GH}^G > 0 \quad (\text{where } \pi_{XH}^G \\ &= 0)\end{aligned}$$

Similarly, we can prove that:

$$\begin{aligned}\frac{\partial q_G}{\partial \rho_G} < 0, \quad \frac{\partial q_X}{\partial \rho_G} < 0, \quad \frac{\partial q_H}{\partial \rho_G} > 0, \\ \frac{\partial q_X}{\partial \rho_X} < 0, \quad \frac{\partial q_H}{\partial \rho_X} > 0, \quad \frac{\partial q_G}{\partial \rho_X} < 0.\end{aligned}$$

²⁸ For example, in the PRD region, Guangzhou Baiyun International Airport also serves as the gateway airport, and competes for both passengers and cargos with Hong Kong International Airport.

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