# Hub Charges and Ownership Structures

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**Abstract**

This paper considers international transport markets where oligopolistic carriers operate rival hub-and-spoke networks. The main contribution is to show that privatization can be considered as a precommitment by the government to charge higher prices for the use of infrastructure and that privatization can, therefore, have positive welfare effects on the local levels. Numerical simulations show that these positive welfare effects can be reduced by foreign carrier ownership.

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# 1 Introduction

It is well known that precommitting to a best-response function with higher prices can lead to higher prices in equilibrium and higher profits (e.g. Fershtman and Judd 1987, Sklivas 1987 and Caillaud and Rey 1995). The main contribution of this paper is to show that privatization can be considered as a precommitment by the government to charge higher prices for the use of infrastructure and that privatization can, therefore, have positive welfare effects on the local levels.

This paper considers international transport markets where carriers operate rival hub-and-spoke networks. These market structures can be observed in sea transport markets, where shipping lines carry containers from China, Japan, the Philippines, Thailand and Vietnam via seaports in Hong Kong, Korea (Busan), Malaysia (Tanjung Pelepas) and Singapore to Europe and North America (Huang et al. 2008). They can also be found in international air transport markets—e.g. European travelers fly to destinations all over the world via hub airports in the UK (London), Germany (Frankfurt), France (Paris) and the Netherlands (Amsterdam). While competition between hubs increases, liberalization of transport markets has also gained momentum. More specifically, this refers to private infrastructure ownership, carrier market entry and foreign carrier ownership.

The model is developed in two steps. In a first step, a two-stage game with a single public hub, oligopolistic carriers and two types of passengers—local and foreign passengers—is considered. In the first stage, the hub charge is chosen to maximize the local welfare of the hub region by incorporating the carriers' behavior in the second stage, where carriers are in Cournot competition. This setting is used to identify the relationships between the local welfare-optimizing hub charge, carrier market structure, passenger types and foreign carrier ownership. In a second step, a rival hub region is introduced. Hub competition is modeled as a supermodular game (it is assumed that the hubs' Bertrand best-responses are increasing in the rivals hub charge; this assumption is verified for linear demands). To elaborate on the welfare effects of public versus private (but not foreign) hub ownership, hubs always attach weights equal to one to hub profits, while the weights attached to consumer surplus and carrier profits (called "ownership parameters") can change. The outcome with public hubs is reached when the ownership parameters are equal to one. On the other hand, the outcome with private hubs is reached when the ownership parameter is reduced and reaches zero. The question is how hub charges and local welfares vary as the ownership parameters are changed when it is abstracted away from price discrimination between passenger types and congestion.

The main result is that private hubs can reach the collusive outcome of public hubs. To understand when this occurs, note that an increase of the hub charge in one region always reduces consumer surplus and carrier profits inside the same region, while the welfare effect of a higher hub charge on the rival region can be positive or negative. Then, if public hubs collude and the welfare effects of hub charges on the rival regions are equal to the absolute effects on their own passengers and carriers, private hubs can reach the collusive outcome of public hubs. The intuition is that privatization is a precommitment by the government to charge higher prices for the use of hubs, which maximizes the total welfare of hub regions given that the previously mentioned conditions are satisfied. Numerical simulations indicate that the welfare gains of privatization are reduced by foreign carrier ownership. This is because public hub charges move closer to the level of their private counter parts when foreign carrier ownership exists.

This paper is closely related to the literature on "strategic delegation", which explores the effects of contracts between firms in oligopolistic markets and third parties (managers) on profits (e.g. Schelling 1960, Vickers 1985, Fershtman and Judd 1987, Sklivas 1987, Fershtman et al. 1991, Katz 1991, Corts and Neher 2003 and Spagnolo 2005). Das (1997) examines the relationship between strategic delegation and trade policy from the policy viewpoint. This paper also takes the policy perspective and shows that delegating infrastructure control to private shareholders can increase social welfare.

This paper is also related to a growing literature on gateway (e.g. ports and airports) and road pricing. De Borger et al. (2005 and 2007) study road congestion pricing on parallel and serial networks where connections are tolled by different governments. To our knowledge, they were the first to distinguish between local and transit traffic and analyze tax competition between two local welfare-maximizing governments. De Borger et al. (2008), consider two congested ports that share the same customers and have each a congested link to a common hinterland. In the first stage, local governments independently and simultaneously choose the port and hinterland capacity, while ports independently and simultaneously choose prices to maximize port profits in the second stage. Yuen et al. (2008) elaborate on a scenario with one gateway, oligopolistic carriers and a congested hinterland, where the gateway chooses prices to maximize the sum of gateway and carrier profits, and the road charges are chosen to maximize the hinterland's welfare.

These studies typically concentrate on atomistic users. Only Yuen et al. consider oligopolistic carrier markets by imposing the strong assumption that ports maximize the sum of port and carrier profits, while none of the mentioned studies compares the welfare effects of public versus private infrastructure ownership. This paper contributes to this strand of the literature in two ways. First, by considering oligopolistic carriers and gateways that maximize local welfares where the social weight of carriers depends on foreign carrier ownership. Second, by studying the implications of public versus private infrastructure ownership on the local welfares of hub regions. This paper also contributes to the literature on the liberalization and regulation of infrastructure, which concentrates on the efficiency of private operators relative to public operators and access pricing until now (e.g. Kessides 2004 and Armstrong and Sappington 2006). The contribution here is that the social benefits of infrastructure privatization that are related to pricing are derived.

Section 2 introduces the basic model with a monopoly hub. Section 3 analyzes the effects carrier market structures, foreign passengers and foreign carrier ownership on hub charges. Section 4 considers two rival hubs to analyze the effects of private versus public infrastructure ownership on hub charges and local welfares. Section 5 provides concluding remarks and a discussion of the results.

# 2 The Model

The basic setting introduced in this section is used to analyze the effect of transfer passengers and carrier market entry on hub charges. Suppose that the supply side encompasses a vertical structure with a *single public hub* and symmetric carriers in Cournot competition. This hub is located in region 1. There also is a second region without hub. Without loss of generality, it can be assumed that the hub operator charges a fee denoted by $\tau_1$ to carriers (not to passengers). The hub's per passenger costs are constant and denoted by $c_1 \geq 0$.[1]

Carriers provide round trips in two markets one local market and one foreign market. In the local (foreign) market, carriers carry the passengers from their location inside region 1 (the foreign region) to hub 1 and then from there to the final destinations and back on the same route.[2] The second market is called "foreign" because these passengers are foreigners from the perspective of region 1, where the hub is located. Denote the number of carriers that operate in the local (foreign) market by $K_1 \geq 1$ ($M_1 \geq 1$), where relatively great carrier numbers may stand for a liberalized market environment. Carriers may operate in the local and the foreign market at the same time. In this situation, the two business areas are considered as separated businesses provided by different entities that may belong to the same company, however.

Passenger fares in the local (foreign) market are denoted by $p_1^l$ ($p_1^f$). Let $q_{1k}^l$ ($q_{1m}^f$) denote the number of local (foreign) passengers carried by a single carrier for $k = 1, \ldots, K_1$ ($m = 1, \ldots, M_1$) and $q_1^l$ ($q_1^f$) denote the total number of local (foreign) passengers ($q_1^x = \sum_y q_{1y}^x$ for $(x, y) \in \{(l, k), (f, m)\}$). The relationship between passenger numbers and fares are determined by inverse demands $P_1^l(q_1^l)$ and $P_1^f(q_1^f)$ with $(P_1^l)', (P_1^f)' < 0$ ($p_1^l = P_1^l(q_1^l)$, $p_1^f = P_1^f(q_1^f)$). Carrier costs are determined by hub charges, while other carrier costs are

[1]This paper abstracts away from increasing returns to scale, which are of relevance for most infrastructures. This is to concentrate on the relationship between infrastructure pricing and ownership structures.

[2]To concentrate on hub services, this paper abstracts away from non-stop connections between the passengers' locations and their final destinations. For simplicity, it is further abstracted away from passengers originating from destination areas and from strategic relationships with hubs located in the destination areas.

normalized to zero.[3] Suppose further that carriers are operated and owned by locals. This assumption will be relaxed soon in the next section.

A two-stage game is considered. In the first stage, the hub charge is chosen to maximize the local welfare of region 1 by incorporating carriers' behavior in the second stage, where the carriers are in Cournot competition. The game is solved by backward induction.

# 3 Single-Hub Case

Before investigating the carrier equilibrium in the second stage, the welfare-optimal solution from region 1's perspective is considered as a benchmark and to illustrate the relevance of the carrier market structures. Region 1's local welfare is determined by the local consumer surplus, the hub profit and carrier profits. This local welfare is independent of the foreign passengers' surplus, while the hub profits incorporate the revenues and costs associated with foreign passengers.

The consumer surplus generated in the hub region's local market can be written as

$$CS_1 = \int_0^{q_1^l} P_1^l \, dx_1 - q_1^l P_1^l \tag{1}$$

and the hub profit as

$$\Pi_1 = (q_1^l + q_1^f)\,(\tau_1 - c_1). \tag{2}$$

Carrier profits are determined by fares and the hub charge. Let $\pi_{1k}^l$ ($\pi_{1m}^f$) denote the profit of a single carrier in the local (foreign) market with

$$\pi_{1y}^x = (P_1^x - \tau_1)\, q_{1y}^x \tag{3}$$

[3] This simplifying assumption on carrier costs is not crucial for the results derived in this paper.

for $(x, y) \in \{(l, k), (f, m)\}$, $k = 1, \ldots, K_1$ and $m = 1, \ldots, M_1$. Since all carriers are supposed to belong to region 1, region 1's welfare can be written as

$$W_1 = \int_0^{q_1^l} P_1^l \, dx_1 + q^f P^f - (q_1^l + q_1^f) \, c_1. \tag{4}$$

To ensure that a unique welfare maximum exists for region 1, assume that

$$\frac{\partial^2}{\partial (q_1^x)^2} \left(P_1^x \times q_1^x\right) = 2(P_1^x)' + (P_1^x)'' q_1^x < 0 \tag{5}$$

for $x \in \{l, f\}$ (the second derivatives of aggregated revenues with respect to passenger numbers are negative). This implies that the marginal aggregated revenues are declining in passenger numbers and that the hub region's welfare, $W_1$, is strictly quasiconcave in the number of local and foreign passenger numbers. Assume further that the welfare-optimal passenger numbers are determined by the first-order conditions

$$\frac{\partial W_1}{\partial q_1^l} = P_1^l - c_1 = 0 \quad \text{and} \quad \frac{\partial W_1}{\partial q_1^f} = P^f + \left(P^f\right)' q^f - c_1 = 0. \tag{6}$$

The hub region's welfare is, thus, maximized when fares are equal to marginal cost in the local market, while marginal aggregated revenues must be equal to marginal costs in the foreign market. Thus, from the public viewpoint of hub region 1, fares should be competitive in the local market and monopolistic in the foreign market.

## 3.1 Carrier Cournot-Nash equilibrium

The hub operator does not directly control passenger numbers but only controls the hub charge. This is because passenger numbers are determined by carriers, which take the hub charge as given. The carrier Cournot-Nash equilibrium is derived next. Assume that the carriers' choice of passenger numbers is determined by the first-order conditions

$$\frac{\partial \pi_{1y}^{x}}{\partial q_{1y}^{x}} = P_1^x + \left(P_1^x\right)' q_{1y}^{x} - \tau_1 = 0 \tag{7}$$

for $x \in \{l, f\}$ and $y = 1, \ldots, Z$ ($Z \in \{K_1, M_1\}$). This gives rise to:

**Lemma 1** *In a scenario with a single hub it holds: (i) There is a unique carrier Cournot-Nash equilibrium in both the local and the foreign market. (ii) There are negative relationships between equilibrium passenger numbers and the hub charge in both the local market and the foreign market.*

**Proof** See Appendix A ■

There is a negative relationship between hub charges and passenger numbers for each market; it directly follows that there is a negative relationship between the total number passengers and the hub charge as well ($d(q_1^l + q_1^f)/d\tau_1 < 0$). Since hub charges determine carrier costs, the negative relationship between hub charges and passenger numbers replicates a well established result.

## 3.2 The local welfare-optimizing hub charge

To ensure the existence of a (unique) solution for the local welfare-optimal hub charge that maximizes region 1's welfare, assume that $d^2W_1/d\tau_1^2 < 0$.[4] Assume further that the hub charge is determined by the first-order condition

$$\frac{dW_1}{d\tau_1} = \left(P_1^l - c_1\right)\frac{\partial q_1^l}{\partial \tau_1} + \left(P^f + q^f\left(P^f\right)' - c_1\right)\frac{\partial q_1^f}{\partial \tau_1} = 0. \tag{8}$$

[4]The value of $\tau_1$ is unbounded; thus, when $d^2W_1/d\tau_1^2 > 0$, there would be no solution for the problem of welfare maximization.

Letting $\varepsilon_1^x$ denote the (endogeneous and positive) elasticity of passenger demand with respect to fares for $x \in \{l, f\}$ ($\varepsilon_1^x = -1/(P_1^x)' \times P_1^x/q_1^x$), this gives rise to:

**Proposition 1** *In a scenario with a single public hub and where all carriers belong to the hub region: (i) If and only if the local carrier market is atomistic and the foreign carrier market is monopolistic, the welfare-optimal passenger numbers that maximize the hub region's welfare can be reached. (ii) The welfare-optimal hub charge can be decomposed as follows:*

$$\tau_1 = c_1 - \frac{d\tau_1}{d(q_1^l + q_1^f)} \left[ \frac{P_1^l}{\varepsilon^l K_1} \frac{dq_1^l}{d\tau_1} - \left(1 - \frac{1}{M_1}\right) \frac{P^f}{\varepsilon^f} \frac{dq_1^f}{d\tau_1} \right]. \tag{9}$$

**Proof** See Appendix B. ■

The RHS of (9) consists of three terms, with a clear interpretation. The first term is equal to the hub's per passenger cost. The second term is negative in sign and determines a subsidy that corrects for carrier market power in the local market. Observe that carrier market power is zero when elasticities are infinite and that subsidies vanish in this situation.[5] The third term is positive in sign and is introduced to optimally exploit foreign passengers. If the absolute value of the market power correction exceeds the extra charge associated with the foreign market, the optimal hub charge will be less than the hub's operating cost, implying a subsidy to carriers in both markets.[6] If $K_1 \to \infty$ and $M_1 = 1$, the RHS of (9) reduces to $c_1$ and implies the welfare-optimal passenger numbers, which are determined by the first-

[5]While demand elasticities with respect to the full price are generally finite in reality, researchers (e.g. Brueckner and van Dender 2008, Brueckner 2009 and Basso and Zhang 2010) have considered models with perfectly elastic demands.

[6]Also see, e.g., Pels and Verhoef (2004) and Zhang and Zhang (2006), who obtained similar results in the context of airport congestion pricing.

order conditions in (6). Otherwise, the welfare-optimal number of passengers cannot be reached.

## 3.3 Foreign carrier ownership

In a liberalized market environment, carriers may belong to foreign shareholders. To identify the effect of foreign carrier ownership, parameters denoted by $\alpha^x \in [0,1]$ for $x \in \{l, f\}$ are introduced. There are two ways to interpret $\alpha^x$. One way is to consider $\alpha^x$ as a constant share of foreigners in carriers. Alternatively, $\alpha^x$ may determine the number of carriers that belong to foreigners given by $\alpha^x Z$ with $(x, Z) \in \{(l, K_1), (f, M_1)\}$ (the number of carriers under local ownership would then be $(1-\alpha^x) \times Z$). In general, greater values of $\alpha^x$ may stand for a more liberalized market environment.

In this scenario, hub region 1's welfare can be written as

$$W_1 = \int_0^{q_1^l} P_1^l \, dx_1 - q_1^l P_1^l + \Pi_1 + \left(1 - \alpha^l\right) \pi_1^l + \left(1 - \alpha^f\right) \pi_1^f, \qquad (10)$$

which reduces to welfare in (4) for $\alpha^l = \alpha^f = 0$. To ensure the existence of a solution, it is assumed that $d^2 W_1 / d\tau_1^2 < 0$ is still satisfied. This yields:

**Proposition 2** *In a scenario with a single public hub, there is a positive relationship between foreign carrier ownership and the hub charge that maximizes the hub region's welfare.*

**Proof** To demonstrate the positive relationship between foreign carrier ownership and the optimal hub charge, it is shown in two steps that $d^2 W_1 / d\tau_1 d\alpha^x > 0$. First, it holds $dW_1 / d\alpha^x = -\pi_1^x$. Second, the envelope theorem implies $d^2 W_1 / (d\tau_1 d\alpha^x) = q_1^x$, where the right-hand side (RHS) is nonnegative. ■

In a liberalized market where some carriers belong to foreigners, the hub region's local welfare is, thus, increased by charging a greater price for the use of hub infrastructure relative to the absence of foreign carrier ownership.

# 4 Hub Competition

The previous section considered a single public hub, and in this setting, the privatization of hub infrastructure is not an issue. This is because a change of hub ownership would change the hub's objectives and reduce local welfare. In this section, two hub regions are considered, which changes the picture. The objective is to show that local welfares of rival hub regions can be greater when hubs are operated by private shareholders and not by the public. To show this, ownership parameters are introduced to benchmark the behavior of public and private hubs against the behavior of colluding public hubs. These benchmarks are useful, since private hubs can never do worse than public hubs from the hub regions' perspective, when they maximize the total welfare of hub regions.

The second hub region is called hub region 2. Assume that local passengers always choose to travel via their regional hub; thus, each hub is provided with an uncontested local hinterland. Hubs can also be provided with uncontested hinterlands in the foreign market, while it is assumed that some foreign passengers choose to travel via hub 1 or hub 2. Denote the number of foreign passengers who travel via hub 2 by $q_2^f \geq 0$ and the inverse foreign demand for trips via hub 2 by $P_2^f$ with $\partial P_i^f / \partial q_i^f < \partial P_i^f / \partial q_j^f < 0$ for $i = 1, 2$ and $j \neq i$. This implies that trips via hub 1 or 2 are substitutes. In this scenario, an increase of the number of foreign passengers who travel via hub $i$ is associated with a reduction of the fares for trips via hub $i$. This would invite foreign passengers to switch from hub $j$ to hub $i$, and inverse demands, therefore, must be reduced for both regions although foreign passengers are increased in only one region.

The number of carriers that operate in the foreign market is $M_1 + M_2$, where $M_i \geq 1$ $(i = 1, 2)$ denotes the number of carriers that serve foreign passengers via hub $i$. All $M_i$ carriers that serve foreign passengers via hub $i$ are symmetric, while carriers that serve foreign passengers via alternative hubs cannot be considered as symmetric because of the differentiation in geography. In the first stage of the game, hubs 1 and 2 simultaneously and independently choose hub charges to maximize local welfares by incorporating the carriers' behavior in the second stage, where the carriers are in Cournot competition.

The following linear demand system will be used to provide evidence for some assumptions applied throughout the analysis and for illustrations.

**Example 1 (Linear demands):** *Hub regions are symmetric with*

$$\frac{\partial^2 P_i^f}{\partial (q_i^f)^2} = \frac{\partial^2 P_i^f}{\partial q_i^f \partial q_j^f} = 0 \tag{11}$$

*for* $i = 1, 2$.

## 4.1 Carrier Cournot-Nash equilibria

Since individuals who are located inside the hub regions always choose their local hub, the equilibrium results for local passengers in hub region 1 derived in Section 3 also hold for hub region 2. Turning to the foreign market, carrier profits in the foreign market are $\pi_{im}^f = (P_i^f - \tau_i)\, q_{im}^f$ for $i = 1, 2$, where the index $i$ indicates whether carriers serve foreign passengers via hub

1 or 2. Assume that the carriers' Cournot best-responses are determined by the first-order conditions

$$\frac{\partial \pi_{im}^{f}}{\partial q_{im}^{f}} = P_i^f - \tau_i + \frac{\partial P_1^f}{\partial q_{im}^f} \, q_{im}^f = 0 \tag{12}$$

for $i = 1, 2$ and $m = 1, \ldots, M_i$. To derive the relationships between hub charges and foreign passenger numbers, it is assumed that

$$\frac{\partial P_i^f}{\partial q_i^f} + \frac{\partial^2 P_i^f}{\partial (q_i^f)^2} \, q_i^f < \frac{\partial P_i^f}{\partial q_j^f} + \frac{\partial^2 P_i^f}{\partial q_1^f \partial q_2^f} \, q_i^f < 0 \tag{13}$$

for $j \neq i$. This implies that the relationship between marginal carrier revenues generated by foreign passengers reacts more sensitive, in absolute values, to changes in the number of foreign passengers traveling via the regional hub relative to changes in the number of foreign passengers traveling via the rival hub (the linear example satisfies this assumption). Furthermore, denote

$$\Xi \;=\; \det \begin{pmatrix} \frac{\partial^2 \pi_{1m}^f}{\partial \left(q_{1m}^f\right)^2} + (M_1 - 1) \, \frac{\partial^2 \pi_{1m}^f}{\partial q_{1m}^f \partial q_{1s}^f} & M_2 \frac{\partial^2 \pi_{1m}^f}{\partial q_{1m}^f \partial q_{2m}^f} \\ M_1 \frac{\partial^2 \pi_{2m}^f}{\partial q_{2m}^f \partial q_{1m}^f} & \frac{\partial^2 \pi_{2m}^f}{\partial \left(q_{2m}^f\right)^2} + (M_2 - 1) \, \frac{\partial^2 \pi_{2m}^f}{\partial q_{2m}^f \partial q_{2s}^f} \end{pmatrix}$$

and assume that $\Xi > 0$. This leads to:

**Lemma 2** *In a scenario with two rival hub regions it holds: (i) There is a unique Cournot-Nash equilibrium in the foreign carrier market. (ii) There is a negative relationship between the number of foreign passengers in region $i$ and the hub charge in region $i$, a positive relationship between the number of foreign passenger in region $j$ and the hub charge in region $i$, and a negative relationship between hub charges and the total number of passengers.*

**Proof** See Appendix C. ■

The assumption that $\Xi$ is nonnegative can be verified for the linear example:

**Example 2 (Linear demands):** *In this example,*

$$\Xi = (2M_i + 1) \times \left(\frac{\partial P_i^f}{\partial q_i^f}\right)^2 + M_i^2 \times \left[\left(\frac{\partial P_i^f}{\partial q_i^f}\right)^2 - \left(\frac{\partial P_j^f}{\partial q_i^f}\right)^2\right], \qquad (14)$$

*which is strictly positive because $\partial P_i^f/\partial q_i^f < \partial P_i^f/\partial q_j^f$ by assumption. The RHS of (14) further implies a positive relationship between $\Xi$ and the number of carriers, $M_i$.*

## 4.2 The social choice of hub charges

This part concentrates on the hubs' Bertrand best-responses to obtain first results on the collusive hub charges relative to a scenario where hub charges are determined in a noncooperative way. Equilibrium hub charges in an environment where hubs operate independently are analyzed in the next part.

In region 2, the hub profit is $\Pi_2 = (\tau_2 - c_2)\,(q_2^l + q_2^f)$, where $q_2^l$ determines the number of local passengers and $c_2$ per passenger costs, and the consumer surplus is $CS_2 = \int_0^{q_2^l} P_2^l \, dx_2 - q_2^l P_2^l$. Letting $W_2$ denote the local welfare in hub region 2, the total welfare of hub regions 1 and 2 can be written as

$$\sum_i W_i = \sum_i \left[\Pi_i + \left(CS_i + \pi_i^l + \pi_i^f\right)\right]. \qquad (15)$$

Assume that this total welfare is strictly quasiconcave in hub charges $\tau_1$ and $\tau_2$ and that the collusive choice of hub charges is determined by the first-order conditions $\frac{d}{d\tau_i}\sum_j W_j = 0$ for $i = 1, 2$, which can be written as

$$\frac{dW_i}{d\tau_i} + \frac{d(P_j^f - c_j)\, q_j^f}{d\tau_i} = 0 \tag{16}$$

for $j \neq i$, where the second term on the left-hand side (LHS) displays the effect of changes in the hub charge $\tau_i$ on hub region $j$'s welfare ($dW_j/d\tau_i$). On the other hand, assume that the hubs' Bertrand best-responses are determined by the first-order conditions $dW_i/d\tau_i = 0$ for $i = 1, 2$ when there is no collusion between hub regions. To ensure the existence of best responses, it is assumed that $d^2W_i/d\tau_i^2 < 0$ for $i = 1, 2$.

To maximize the total welfare of hub regions, each region must consider the effect hub charges have on the rival region's profit in the foreign market, which is determined by the second term on the LHS of (16). The sign of this second term can be positive or negative. More specifically, if $P_j^f - c_j \geq 0$ and

$$\frac{\partial P_j^f}{\partial q_i^f}\,\frac{\partial P_j^f}{\partial q_j^f} > q_j^f \left( \frac{\partial^2 P_j^f}{\partial q_j^f \partial q_i^f}\,\frac{\partial P_j^f}{\partial q_j^f} - \frac{\partial^2 P_j^f}{\partial (q_j^f)^2}\,\frac{\partial P_j^f}{\partial q_i^f} \right), \tag{17}$$

this term is always positive (see Appendix D). This gives rise to:

**Proposition 3** *In a scenario with two rival hub regions and given that the condition in (17) is satisfied, the best response of hub region i with respect to the hub charge j is increased by collusion (relative to a scenario where hubs concentrate on local welfares) if $P_j^f \geq c_j$, while the effect of collusion on best responses can be positive, negative or zero otherwise.*

**Proof** See Appendix D. ■

Foreign passengers are subsidized when fares are below costs ($P_i^f < c_i$). Recall that the welfare-optimal charge of a single hub can be smaller than costs to correct for market power in the local market (Proposition 1). The dupolistic hub charges can be below costs for the same reason, which can lead to situations where fares in the foreign markets are below costs. In these situations, an increase of one hub charge can increase subsidy payments to foreign passengers in the rival region. As a consequence, the collusive hub charges can be smaller than the competitive ones. The effect of collusion on equilibrium hub-charges relative to the competitive hub charges can, therefore, be positive or negative in sign.[7]

The linear example provides evidence that market environments exist, where the conditions in (17) are satisfied.

**Example 3 (Linear demands):** *With linear demands, the relationships in (17) are satisfied. Thus, in this scenario, collusion increases the hubs' Bertrand best-responses when* $P_i^f - c_i > 0$.

*To illustrate the relationship between hub charges and competition versus collusion, suppose that* $K_i = M_i = 1$, $c_i = 0$ *for* $i = 1, 2$ *and that inverse demands are*

$$P_i^l = 15 - q_i^l \quad \textit{and} \quad P_i^f = 1 + \frac{a}{2} - \frac{1}{7}\left(4\, q_i^f + 3\, q_j^f\right), \tag{18}$$

*where* $a \geq 0$ *determines the market size of the foreign market. In this instance, the competitive and collusive hub charges are*

$$\tau_i = -\frac{1}{939}\,(3109 + 42\,a) \quad \textit{or} \quad \tau_i = -\frac{1}{171}\,(577 - 14\,a), \tag{19}$$

[7] It is well known that collusion can lead to lower fares relative to the competitive level when services are strategic complements (e.g. Brueckner 2001 and Czerny 2009). By contrast, the case with rival hubs considered in this paper incorporates strategic substitutes, since $\partial P_i^f / \partial q_j^f < 0$ by assumption.

*respectively. The comparison of these hub charges reveals that collusion exerts downward pressure on hub charges when $a < 1/2$.*

There is a difference between the setting with a single hub and the setting of two rival hub regions that should be explicitly mentioned. With a single hub, the welfare maximum of hub region 1 can be achieved when the local carrier market is atomistic and the foreign carrier market is monopolistic (Proposition 1). In the current setting, a similar welfare result cannot be achieved because the possibility that a single carrier exists in the foreign market is ruled out by assumption ($M_i \geq 1$ for $i = 1, 2$). Hence, even when hub regions collude, the number of passengers that maximize the hub regions' welfare cannot be achieved because of carrier competition.

### 4.3 Public versus private hub ownerships

To analyze equilibrium hub charges and the effect of ownership structures, assume that the hubs' objectives denoted by $\Omega_i$ are determined by *ownership parameters* $\beta_i$ with

$$\Omega_i = \Pi_i + \beta_i \left( CS_i + \pi_i^l + \pi_i^f \right) \tag{20}$$

for $i = 1, 2$. In this scenario, hub $i$'s objective is to maximize hub profits when $\beta_i = 0$, which stands for a fully privatized hub infrastructure (private and local hub ownership).[8] On the other hand, the objective is to maximize local welfare $W_i$ when $\beta_i = 1$, which stands for public hub ownership.

Assume that hub charges are determined by the first-order conditions

$$\frac{d\Omega_i}{d\tau_i} = \frac{d\Pi_i}{d\tau_i} + \beta_i \frac{d\left(CS_i + \pi_i^l + \pi_i^f\right)}{d\tau_i} = 0 \tag{21}$$

[8] It is abstracted away from foreign hub ownership.

for $i = 1, 2$. To ensure the existence of a unique equilibrium, it is assumed that

$$\frac{d^2\Omega_i}{d\tau_i^2} < 0 \quad \text{and} \quad \left|\frac{d^2\Omega_i}{d\tau_i^2}\right| > \left|\frac{d^2\Omega_i}{d\tau_i d\tau_j}\right| \tag{22}$$

for $j \neq i$ (e.g. Vives 1999). The strategic relationship between hub regions 1 and 2 can be considered as a supermodular game when the objectives exhibit increasing differences ($d^2\Omega_i/d\tau_i d\tau_j > 0$ for $j \neq i$), which would imply that hub charges are strategic complements. If foreign fares are greater than costs, it is natural to assume increasing differences because there is a positive relationship between the rival's hub charge and foreign passenger numbers by Lemma 2. If foreign fares are below costs, increasing differences may also occur because an increase of the rival's hub charge raises the number of foreign passengers, which can lead to higher subsidy payments. In this situation, an increase of the hub charge can increase the hub's objective because it reduces subsidy payments to foreign passengers. The following example shows that increasing differences exist when demands are linear.

**Example 4 (Linear demands):** *The hubs' objectives exhibit increasing differences ($d^2\Omega_i/d\tau_i d\tau_j > 0$ for $j \neq i$) when*

$$M_i^2 > \frac{\left(\frac{\partial P_i^f}{\partial q_i^f}\right)^2 \times \frac{\partial P_i^f}{\partial q_j^f} - \Xi \times (1 - \beta_i)\,\frac{\partial P_i^f}{\partial q_j^f}}{\left(\frac{\partial P_i^f}{\partial q_i^f}\right)^2 \times \frac{\partial P_i^f}{\partial q_j^f} - \left(\frac{\partial P_i^f}{\partial q_j^f}\right)^3}. \tag{23}$$

*The RHS is negative in sign when $\beta_i = 1$ and further decreases when $\beta_i = 0$ because there is a positive relationship between $\Xi$ and $M_i$ by (14). Hence, differences, $d\Omega_i/d\tau_i$, are increasing in $\tau_j$ ($j \neq i$), which holds for all $K_i, M_i \geq 1$ and all $(\beta_1, \beta_2) \in [0, 1] \times [0, 1]$.*

Assume that the hubs objectives $\Omega_i$ exhibit increasing differences with respect to $\tau_i$ and $\tau_j$ for $j \neq i$. It is useful to define different degrees of private involvement. In the following, private involvement is the lowest when the two hubs are public ($\beta_1 = \beta_2 = 0$), intermediate when only one hub is private ($\beta_i = 0, \beta_j = 1$ with $j \neq i$), and the greatest when the two hubs are private ($\beta_1 = \beta_2 = 1$). This gives rise to:

**Proposition 4** *In a scenario with two rival hub regions, equilibrium hub charges are positively related to the private involvement in hub operations.*

**Proof** See Appendix E. ∎

The privatization of hub infrastructure can, thus, be considered as a commitment to charge greater hub charges in the future. Recall that the hub's best responses can be greater with collusion (Proposition 3), which indicates that hub regions may be able to achieve the collusive outcome by the privatization of hub infrastructure. To see under which conditions this is true denote

$$\Psi_i = \frac{d(P_j^f - c_j)\, q_j^f / d\tau_i}{-d(CS_i + \pi_i^l + \pi_i^f)/d\tau_i} \tag{24}$$

for $i = 1, 2$. The numerator displays the effect of region $i$'s hub charge on region $j$'s welfare ($dW_j/d\tau_i$). Recall that the effect of region $i$'s hub charge on region $i$'s consumer surplus and region $i$'s carrier profits is negative in sign (proof of Proposition 4). The denominator on the RHS of (24), therefore, displays the absolute effect of region $i$'s hub charge on region $i$'s consumer surplus and region $i$'s carrier profits. This leads to:

**Proposition 5** *In a scenario with two rival hub regions it holds: (i) If the collusive outcome implies $\Psi_i = 0$ for $i = 1, 2$, the collusive outcome is achieved by public hubs; (ii) if the collusive outcome implies $\Psi_i = 1$ for*

$i = 1, 2$, *the collusive outcome is achieved by private hubs; (iii) if the collusive outcome implies* $\Psi_i = 0$ *and* $\Psi_j = 1$ *for* $j \neq i$, *the collusive outcome is achieved when hub* $i$ *is public and hub* $j$ *is private.*

**Proof** Setting the first-order conditions in (16) and (21) equal and solving for $\beta_i$ shows that the independent choice of hub charges implies the collusive outcome only if $\beta_i = 1 - \Psi_i$ for $i = 1, 2$. ■

The results stated in Proposition 5 hold under relatively general conditions, since they are independent of the supermodularity property. The following numerical instance illustrates the welfare effects of privatization.

**Example 5 (Linear demands):** *To derive numerical results, inverse demands in the local and foreign markets are specified as*

$$P_i^l = 1 - q_i^l \quad \textit{and} \quad P_i^f = 2 - \frac{1}{11}\left(8\, q_i^f + 3\, q_j^f\right) \tag{25}$$

*with* $j \neq i$. *Table 1 displays the outcomes for public and private hubs when hubs simultaneously and independently choose hub charges. The local markets are assumed to incorporate a duopolistic carrier market (*$K_i = 2$ *for* $i = 1, 2$*), while the number of carriers in the foreign market sums up to 10 (*$M_i = 5$ *for* $i = 1, 2$*). These parameters ensure that the collusive outcome can be achieved by the privatization of hub infrastructure. Table 1 shows that the private hub charges are significantly greater than the hub charges that occur when hubs are public. It further shows that the welfare gains from infrastructure privatization are substantial (around 8%).*

Altogether, this shows that privatization can be considered as a precommitment by the government to charge higher prices for the use of hub infrastructure and that privatization can, therefore, have positive welfare effects

|  | $\tau_i$ | $W_i$ | $\Pi_i$ | $\pi_i^l$ | $\pi_i^f$ | $q_i^l$ | $q_i^f$ |
|---|---|---|---|---|---|---|---|
| Public hubs | 0.40 | 1.61 | 0.72 | 0.08 | 0.28 | 0.40 | 1.40 |
| Private hubs | 0.69 | 1.74 | 0.93 | 0.02 | 0.19 | 0.20 | 1.14 |

Table 1: Outcomes when hubs are public or private. Parameters: $K_i = 2, M_i = 5$ for $i = 1, 2$.

on the local levels. Proposition 5 shows the exact conditions under which privatization yields the collusive outcome.

### 4.4 Foreign carrier ownership

To elaborate on the effect of foreign carrier ownership on equilibrium hub charges, the hubs' objectives are written as

$$\Omega_i = \Pi_i + \beta_i \left[ CS_i + \left(1 - \alpha_i^l\right) \pi_i^l + \left(1 - \alpha_i^f\right) \pi_i^f \right] \tag{26}$$

for $i = 1, 2$, where $\alpha_i^x \in [0, 1]$ for $i = 1, 2$ and $x \in \{l, f\}$ determines the foreign shares in carriers. In the current scenario with two hub regions, there are two types of foreign carrier ownerships because carriers can belong to the foreign hub region (cross ownerships) or to the foreign region without hub. The following result is independent of the foreign carrier ownership type.

Assume that the objectives in (26) exhibit increasing differences with respect to $\tau_i$ and $\tau_j$ ($j \neq i$). The relationship between foreign carrier ownership and equilibrium hub charges can then be described as follows:

**Proposition 6** *In a scenario with to rival hub regions, there is a positive relationship between the equilibrium hub charges and foreign carrier ownerships. This holds for both foreign ownership in carriers that operate in the* *local markets and foreign ownership in carriers that operate in the foreign markets.*

**Proof** See Appendix F. ■

This is consistent with the findings on hub charges in the case of a single hub, where a positive relationship between the hub charge and foreign carrier ownerships also exists (Proposition 2).

The distinction of foreign carrier ownership types (cross ownerships between hub regions versus ownerships by the non-hub region) is relevant for the welfare effects of hub privatization. The reason is that the hub regions' total welfare, $W_1 + W_2$, is independent of the carrier ownership structure when cross carrier ownerships exist, which implies that the collusive outcome is independent of cross carrier ownerships as well. On the other hand, total welfare is $\sum_i [W_i - (\alpha_i^l \pi_i^l + \alpha_i^f \pi_i^f)]$ when carrier ownerships by the non-hub region exist. This, thus, establishes a negative relationship between the welfare of hub regions 1 and 2 and foreign carrier ownership, which affects the collusive outcome. Independent of the foreign carrier-ownership type, it can be shown that there are market constellations, where the collusive outcome can be achieved by the appropriate choice of hub ownerships when foreign carrier ownerships exist (the proof is analogous to the proof of Proposition 6).

The following numerical instance illustrates the welfare effects of infrastructure privatization in a scenario where foreign carrier ownership exists:

**Example 6 (Linear demands):** *Table 2 displays the outcomes for public and private hubs when hubs simultaneously and independently choose hub charges given the demand specifications in (25). The local markets incorporate a duopolistic structure ($K_i = 2$), while the number of carriers in the foreign market sums now up to 8 ($M_i = 4$) to ensure that the collusive outcome*

| | $\tau_i$ | $W_i$ | $\Pi_i$ | $\pi_i^l$ | $\pi_i^f$ | $q_i^l$ | $q_i^f$ |
|---|---|---|---|---|---|---|---|
| Public hubs | 0.58 | 1.01 | 0.86 | 0.04 | 0.26 | 0.28 | 1.20 |
| Private hubs | 0.70 | 1.02 | 0.91 | 0.02 | 0.22 | 0.20 | 1.02 |

Table 2: Outcomes when hubs are public or private and when foreign carrier ownership exists (carrier shares belong to the non-hub region; it is abstracted away from cross carrier-ownership). Parameters: $K_i = 2, M_i = 4, \alpha_i^l = 4/10, \alpha_i^f = 9/10$ for $i = 1, 2$.

*can be achieved by the privatization of hub infrastructure. Table 2 shows that the collusive hub charge is greater than the hub charge that occurs when hubs are public, but the difference is smaller relative to the previous scenario (Table 1), which can be explained by the existence of foreign carrier ownership (Proposition 6). The welfare gains from hub privatization or, respectively, collusion are rather small in this scenario.*

# 5 Conclusions

This paper considers oligopolistic carriers operating rival hub-and-spoke networks. It is shown that privatization can implement the collusive of outcome for rival hub regions if the local effect of privatization is equal to the welfare effect of privatization on the rival hub region in absolute values. The reason why such welfare effects can be achieved is that privatization can be considered as a precommitment to charge higher prices for the use of hubs. A highly debated issue is whether precommitments or, respectively, delegation contracts are credible (e.g. Katz 1991 and Corts and Neher 2003). The credibility typically depends on whether contracts are public and not renegotiable.

Although these two conditions are hardly satisfied in many real world cases, the case of infrastructure privatization may be considered as one example where credibility is given. This is because privatization is typically publicly announced and relatively transparent. Moreover, the public involvement may exacerbate renegotiations relative to a situation where only private parties are involved.

# A Proof of Lemma 1

To establish part (i), it is useful to understand that the relationships in (5) imply $\partial^2 \pi^x_{1y} / \partial q^2_{1y} < 0$ for $(x, y) \in \{(l, k), (f, m)\}$. The first-order conditions in (7) are, thus, associated with carrier profit maximization. The relationships in (5) further imply that the carrier Cournot-Nash equilibria are unique in both the local and the foreign market. This is because carrier services are homogeneous and Cournot best-responses for any carrier have negative slopes larger than $-1$ (e.g. Vives 1999).

To establish part (ii), it is useful to understand that individual passenger numbers are $q^x_{1y} = q^x_1 / Z$ in equilibrium ($1/Z$ are market shares), since carriers are symmetric. The carriers' first-order conditions in (7) then imply

$$P^x_1 = \tau_1 - (P^x_1)' \, \frac{q^x_1}{Z} \tag{27}$$

for $(x, Z) \in \{(l, K_1), (f, M_1)\}$ in equilibrium. The relationship between the hub charge and passenger numbers are, therefore, given by

$$\frac{dq_1^x}{d\tau_1} = -\frac{Z\frac{\partial^2 \pi_{1y}^x}{\partial q_{1y}^x \partial \tau_1}}{\frac{\partial^2 \pi_{1y}^x}{\partial \left(q_{1y}^x\right)^2} + (Z-1)\frac{\partial^2 \pi_{1y}^x}{\partial q_{1y}^x \partial q_{1y}^x}} \tag{28}$$

$$= \frac{Z}{Z\left[(P_1^x)' + (P_1^x)''\ \frac{q_1^x}{Z}\right] + (P_1^x)'} < 0 \tag{29}$$

for $(x, y, Z) \in \{(l, k, K_1), (f, m, M_1)\}$ due to the relationships in (5).

# B Proof of Proposition 1

To establish part (i), substitute $P_1^x$ by the RHS of (7) in the first-order condition in (8); rearranging then yields

$$\left(\tau_1 - c_1 - \left(P_1^l\right)' \frac{q_1^l}{K_1}\right)\frac{\partial q_1^l}{\partial \tau_1} + \left(\tau_1 - c_1 + q^f \left(P^f\right)' \left(1 - \frac{1}{M_1}\right)\right)\frac{\partial q_1^f}{\partial \tau_1} = 0. \tag{30}$$

To see that the first-best solution can be reached if the local carrier market is atomistic and the foreign carrier market is monopolistic, suppose that $K_1 \to \infty$ and $M_1 = 1$. In this situation, the first-best solution can be reached for $\tau_1 = c_1$, which implies $\partial W_1/\partial q_1^l = \partial W_1/\partial q_1^f = 0$ and, thus, $dW_1/d\tau_1 = 0$. If $K < \infty$ and $M = 1$, $\partial W_1/\partial q_1^l > 0$ for $\tau_1 = c_1$. Since $dq_1^l/d\tau_1, dq_1^f/d\tau_1 < 0$ by Lemma 1, $\tau_1 < c_1$, $\partial W_1/\partial q_1^l > 0$ and $\partial W_1/\partial q_1^f < 0$ in optimum, which shows that the first-best outcome cannot be reached in this situation. On the other hand, if $K_1 \to \infty$ and $M_1 > 1$, $\tau_1 > c_1$, $\partial W_1/\partial q_1^l > 0$ and $\partial W_1/\partial q_1^f < 0$ in optimum, which shows that, in this situation as well, the first-best outcome cannot be reached. Similarly, $\partial W_1/\partial q_1^l \neq 0$ and $\partial W_1/\partial q_1^f \neq 0$ when $K_1 < \infty$ and $M_1 > 1$ at the same time. The first-best result can, therefore, only be reached when the local market is atomistic and the foreign market is monopolistic. To establish part (ii), solve the first-order condition in (30) for $\tau_1$. Further manipulations and rearrangements then yield the optimal hub charge in (9).

# C Proof of Lemma 2

To establish part (i), it is useful to understand that the relationships in (13) imply $\partial^2 \pi^f_{im}/\partial q^2_{im} < \partial^2 \pi^f_{im}/\partial q_{im} \partial q_{js} < 0$ for $s \neq m$ when $j = i$ and $s = 1, \ldots, M_j$ when $j \neq i$. This further implies that Cournot best-responses for any carrier have negative slopes larger than $-1$ and ensures the existence of a unique Cournot-Nash equilibrium in the foreign carrier market.

To establish part (ii), Cramer's rule is applied to obtain

$$\frac{dq^f_i}{d\tau_i} = \frac{M_i}{\Xi} \left( \frac{\partial^2 \pi^f_{jm}}{\partial (q^f_{jm})^2} + (M_j - 1) \frac{\partial^2 \pi^f_{jm}}{\partial q^f_{jm} \partial q^f_{js}} \right) < 0 \tag{31}$$

for $j \neq i$ and $s \neq m$, while

$$\frac{dq^f_j}{d\tau_i} = -\frac{M_j}{\Xi} M_i \frac{\partial^2 \pi^f_{jm}}{\partial q^f_{jm} \partial q^f_{im}} > 0 \tag{32}$$

for $j \neq i$ and $s \neq m$. The assumptions in (13) and the relationships in (31) as well as (32) imply $\partial (q^f_1 + q^f_2)/\partial \tau_i < 0$ for $i = 1, 2$.

# D Proof of Proposition 3

To understand the relationship between the condition in (17) and the sign of $d(P_j^f - c_j)\, q_j^f / d\tau_i$, note that the latter is positive when

$$P_j^f - c_j \geq -q_j^f \times \left( \frac{\partial P_j^f}{\partial q_j^f} + \frac{\partial P_j^f}{\partial q_i^f} \frac{\partial q_i^f}{\partial \tau_i} \frac{\partial \tau_i}{\partial q_j^f} \right) \tag{33}$$

with $j \neq i$. Substituting $\partial q_i^f / \partial \tau_i$ and $\partial q_j^f / \partial \tau_i$ by the RHSs of (31) and (32) and rearranging shows that the sum of the two terms inside the parentheses is positive when the condition in (17) is satisfied. Thus, if (17) is satisfied and $P_j^f - c_j \geq 0$, the relationship in (33) holds and collusive best-responses are greater than the competitive best-responses, since $\partial^2 W_i / \partial \tau_i^2 < 0$ by assumption. If $P_j^f - c_j < 0$, the relationship in (33) may or may not hold. In these situations, the effect of collusion on Bertrand best-responses can be positive, negative or zero.

# E Proof of Proposition 4

Since the hubs objectives $\Omega_i$ exhibit increasing differences with respect to $\tau_i$ and $\tau_j$ ($j \neq i$), the Bertrand game between hubs is supermodular. If the hubs' objectives exhibit decreasing differences in the hub charge and ownership parameter ($d^2\Omega_i / d\tau_i d\beta_i < 0$ for $i = 1, 2$), the supermodularity property implies a negative relationship between hub charges and ownership parameters in equilibrium. To see that these differences are decreasing, note that the sign of $d(CS_i + \pi_i^l + \pi_i^f)/d\tau_i$ is negative, since the sign of each of its components

$$\frac{dCS_i}{d\tau_i} = -q_i^l \times \left(P_i^l\right)' \frac{\partial q_i^l}{\partial \tau_i}, \; \frac{d\pi_i^l}{d\tau_i} = -q_i^l, \; \frac{d\pi_i^f}{d\tau_i} = q_i^f \times \left( \frac{\partial P_i^f}{\partial q_j^f} \frac{\partial q_j^f}{\partial \tau_i} - 1 \right) \quad (34)$$

is negative. The sign of $dCS_i/d\tau_i$ is negative by Lemma 1 ($dq_i^l/d\tau_i < 0$), while the sign of $d\pi_i^f/d\tau_i$ is negative by Lemma 2 ($dq_j^f/d\tau_i > 0$). The decreasing differences between hub charges and ownership parameters follow.

# F Proof of Proposition 6

The Bertrand game between hubs 1 and 2 is supermodular. If the hubs' objectives exhibit increasing differences with respect to the hub charge and foreign carrier ownership ($d^2\Omega_i/d\tau_i d\alpha_i^x > 0$ for $i = 1, 2$ and $x \in \{l, f\}$), the supermodularity property implies a positive relationship between hub charges and foreign carrier ownerships in equilibrium. To see that these differences are increasing recall that $d\pi_i^x/d\tau_i < 0$ for $i = 1, 2$ and $x \in \{l, f\}$ (see the proof of Proposition 4), which implies $d^2\Omega_i/d\tau_i d\alpha_i^x = -d\pi_i^x/d\tau_i > 0$ for $i = 1, 2$ and $x \in \{l, f\}$.

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