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The Competition among Airlines and its Effect on the Aviation Network

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Abstract:

This paper constructs the three-airport model in which a full-service airline can determine its network configuration. Moreover, the degree of the competition differs among the three routes: namely, the full-service airline faces the intense competition in a thick demand route while other two routes are under the monopoly by the full-service airline. By using this model, we address the following problems: i) how the competition affects the full-service airline's network choice; and ii) to correct the inefficiency of the airline's network choice, what type of the policies is socially preferred. With respect to the policies, we consider the two alternative policies, the direct regulation on the network choice and the transfer among the routes through the universal service fee revenue. By comparing the two policies, it is shown that when the airline forms the point-to-point, the direct regulation is socially preferred while under the hub-spoke, the transfer scheme achieves the higher economic welfare.

Keywords: Airline Competition, Network Choice, Direct Regulation, Universal Service Fee

1. Introduction

Due to a significant decline in the population, Japanese local airports face the problem how to keep the passenger flight service. Indeed, from 2006 to 2015, although the Japanese airport users have increased by 8.47 %, the users of airports with less than 30 flights per day have declined by 7.47 %.[1] To sustain the flight service at local airports, the Japanese government implements the regulation on the flight service between the local airports and the Japanese largest hub, Tokyo International Airport.

[1] Spitz et al. (2015) have reported that, from 2001 to 2013, the small airports in the United States have experienced 32 % decline in the flights, and 17 % decline in the available seats. Although, during the same period, the large hub airports have also faced the decreases in the flights and the available seats, the degree of the decline is less significant than the small airports experienced.

Specifically, the regulation has the following two features: i) airlines cannot convert its slots for the thin demand routes to the thick demand routes; ii) once abolishing the routes to the thin demand airport, its slot is reallocated to other airlines. Under this regulation, ceasing the service to the thin demand routes immediately means the loss of the slots at the largest hub; therefore. this regulation can be interpreted as the policy such that the government directly determines whether to abolish the direct flight service to thin demand routes. This regulation may be justified from the equity as well as from the efficiency perspective; namely, the access to the largest hub can be viewed as an essential service to keep the nation-wide free movement.

In contrast to the aviation market, in the telecommunication market, several countries introduce the universal service fund to maintain the nation-wide service. This policy is implemented because of the deregulation in the telecommunication market. Namely, before the deregulation, the services to the thin demand markets have maintained by the cross subsidy of the nation-wide provider. The deregulation, however, results in the intense competition in the thick demand markets; therefore, the nation-wide provider faces the shortage of the funds for the cross subsidy. Therefore, in order to maintain the service to the thin demand routes, the government collects the fees from each telephone user, and the fee revenue is redistributed to the thin demand markets. Although the aviation market also experiences the deregulation and consequent intense competition in thick demand markets, maintaining the flight service in thin demand markets still depends on the cross subsidy by the network airlines.[2] Between the two alternative policies, the direct regulation and the universal service fee, this paper compares the efficiency gains. Specifically, we address the problems such as i) how the intense competition in a thick demand route affects a full-service airline's network choice and the economic welfare; ii) between the direct regulation and the universal service fee, which policy enhances the economic welfare; and iii) under what circumstance the universal service fee is socially preferred.

Due to the deregulation in the aviation market, several studies deal with the airline's network choice (for example, Brueckner, 2004; Kawasaki, 2008; Flores-Fillol, 2009).[3] They, however, mainly focus on the case where the monopolistic airline, and consequently the effect of the competition in some routes on the entire network is out of

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[2] For network airlines, such as All Nippon Airways (ANA) and Japan Airlines (JAL), the regulation on the slots at Haneda forces to implement the cross subsidy between the thick and the thin demand markets. Indeed, ANA claims that, due to the nationwide population decline and the intense competition in the thick demand routes, it is more difficult to implement the cross subsidy between the thick and the thin demand routes (Ministry of Land, Infrastructure, Transport, and Tourism 2012).

[3] Brueckner (2004) analyzes the topic using three airports and a monopolistic carrier model. The carrier chooses a hub-spoke network when the fixed cost for a flight is high relative to the marginal cost for a seat and when passengers place a high value on flight frequency. Kawasaki (2008) extends the model of Bruechner (2004) by introducing the heterogeneity in value of time among passengers, leisure and business demands. Flores-Fillol (2009) extends the model by considering the duopoly case and shows that asymmetric equilibria may arise, namely one carrier chooses a point-to-point network while the other chooses a hub-spoke network.

consideration. With respect to the regulation at the congested hub airport, the comparison of the slot allocation and the congestion pricing is studied in Bruecner (2009), Basso and Zhang (2010), and Sieg (2010).[4] Although they compare the two alternative policies from the economic welfare perspective, the difference in the demand size among the routes is not considered. Focusing on the Japanese regulation, Teraji and Araki (2016) compares the regulation on the slot and the discount in the landing fee. Although they show that both policies are equivalent in the efficiency perspective, they do not consider the transfer scheme among the passengers traveling different routes. The transfer is considered in Valido et al. (2013), but they focus on the residence based transfer and on a single origin destination pair.

This study constructs the three-airport model in which the demand size differs among the three airports. Furthermore, due to the difference in the demand size, the degree of the competition varies. Specifically, a full-service airline competes in a thick demand route, and the other two routes are under its monopoly. Also, note that the full-service airline enjoys the economies of scope if it serves to more than two routes. By using this model, we deal with how the full-service airline determines its network configuration, and how the competition in the thick demand routes affects the full-service airline's

[4] Other than these studies, Fukui (2010) deals with the problem whether the slot allocation promotes the competition among airlines.

network choice. In addition, to correct the inefficiency of the full-service airline's network choice, we consider the two alternative policies, the direct regulation on the network choice by the full-service airline and the universal service fee. The direct regulation is aimed at maximizing the economic welfare under the circumstance where the airfares and the number of seats (or flights) are determined under the decentralized setting. In contrast, under the universal service fee, the government imposes the different fees on the passengers travelling the different routes while the full-service airline determines its network configuration.

The rest of this paper is organized as follows. Section 2 describes the model. Section 3 summarizes the equilibrium network configuration which is determined by the full-service airline in order to maximize its profit. To measure the inefficiency of the equilibrium network configuration, this section also derives the optimal network configuration. In Section 4, we consider the two alternative policies, the direct regulation and the universal service fee. Through the comparison of the four alternative network configurations, we evaluate the welfare effects of the two policies. In addition, we summarize the condition where the universal service fee scheme is socially desired. Finally, Section 5 concludes.

2. The Model

2.1. The Basic Setting

Suppose an economy which is consisted from the three cities, H, L, and S. The three cities differ in the population size, and we denote by n_i the population of City i ($i = H, L, S$). In addition, we assume that City H is the largest city whereas City S is the smallest. In order to simplify the analysis, we normalize the population of H, n_H, to unity; therefore, $n_H = 1 > n_L > n_S$. Each City i has an airport, and we name the one at City i Airport i. Figure 1 summarizes the geography of this economy, and l_{ij} represents the distance between the two cities, i and j. We assume that Cities L and S are equidistant from City H, and we normalize the distances between City H and Cities L and S to unity (that is, $l_{HL} = l_{HS} = 1$). Moreover, we consider the situation where the distance between Cities L and S, l_{LS}, is at least the same as those between City H and Cities L and S. In order to avoid the notational complexity, we denote by $l \geq 1$ the distance between L and S.

<<Figure 1: ABOUT HERE>>

As in Figure 1, this economy has the three air trip routes. Hereafter, we denote these three by Routes HL, HS, and LS. According to the setup described above, the demand size varies among the three routes, and due to this difference, the degree of the competition also differs among them. Namely, Route HL is under the competition while the other two routes are under the monopoly. Furthermore, we assume that a monopolistic provider serves to the two routes, HS and LS, and it competes in Route HL with other m airlines. Hereafter, we call this monopolistic provider Airline 1. This economy has the three types of agents, Airline 1, other m airlines, and residents. Among the three types, the sequence of the decision is as follows. First, Airline 1 determines its network configuration, and then $m + 1$ airlines chooses the amount of service to be provided along their served routes. Finally, residents in each city i decide whether to travel to the other two cities by using Airport i.

Since Airline 1 serves to all the three routes, Airline 1 can determine its network configuration. In order to express the network choice explicitly, we define by δ_{ij} the binary variable, which shows Airline 1's choice whether to provide the direct flight service to Route ij. Namely, $\delta_{ij} = 1$ if Airline 1 operates the direct flight service along Route ij; $\delta_{ij} = 0$, otherwise. By using δ_{ij}, Airline 1's network choice is represented by the vector $\boldsymbol{\delta} = (\delta_{HL}, \delta_{HS}, \delta_{LS})$. Figure 2 below summarizes the Airline 1's alternative network choices. As in Figure 2, when Airline 1 chooses the hub-spoke network (that is, $\boldsymbol{\delta} = (1,1,0)$), we assume that the hub locates at Airport H.

<<Figure 2: ABOUT HERE>>

The individual trip demand for Route ij is denoted by d_{ij}, and it is specified as:

$$d_{ij} = 1 - p_{ij}. \tag{1}$$

By using Eq. (1), the aggregate demand, D_{ij}, is derived as follows:

$$D_{ij} = \left(n_i + n_j\right) d_{ij} = \left(n_i + n_j\right)\left(1 - p_{ij}\right).$$

Let us denote by Q_{ij} the number of seats for Route ij provided by the airlines. Since, at the equilibrium, $D_{ij} = Q_{ij}$, the inverse demand function for each of three routes, $P_{ij}(Q_{ij})$, is derived as:

$$D_{ij} = Q_{ij} \Leftrightarrow P_{ij}\left(Q_{ij}\right) = 1 - \frac{Q_{ij}}{n_i + n_j}. \tag{2}$$

By using Eq. (2), the consumer surplus of Route ij is computed as:

$$CS_{ij}\left(Q_{ij}\right) = \int_0^{Q_{ij}} P_{ij}\left(x\right) dx - P_{ij}\left(Q_{ij}\right) Q_{ij} = \frac{Q_{ij}^2}{2\left(n_i + n_j\right)}. \tag{3}$$

2.2. Airlines

When providing the direct flight service to the routes, each airline incurs the two types of the cost, the flight operating cost and the fixed cost. The marginal flight operating cost is measured on a per passenger kilometer basis. For Airline 1, the marginal cost differs with its network configuration. Namely, because of the economies of scope, when Airline 1 operates the direct flight service to more than two routes, it can enjoy the scale economy. In other words, the marginal cost under $\boldsymbol{\delta} = (1,1,1)$ or $\boldsymbol{\delta} =$

$(1,1,0)$ is lower than the one under $\boldsymbol{\delta} = (1,0,0)$. In addition, taking the emergence of low cost carriers into consideration, we assume that the marginal cost of Airline 1 is at least as high as that of its competitors. The competitors are symmetric in their technologies; that is, the marginal costs of the competitors are identical. The marginal cost for the competitors is denoted by c, and that for Airline 1 depends on is network configuration. In case of $\boldsymbol{\delta} = (1,1,1)$ or $\boldsymbol{\delta} = (1,1,0)$ Airline 1's marginal cost is c whereas, under $\boldsymbol{\delta} = (1,0,0)$, the marginal cost is denoted by $\gamma c > c$ (that is, $\gamma > 1$).

Other than the direct flight operation cost, airlines incur the fixed cost if they choose to provide the direct flights to a route. This may include the costs such as the operation of the ground services at the airports. Furthermore, the fixed cost for Route HL is lower than those for Routes HS and LS. Namely, we denote by F the fixed cost for HS and LS, and for HL each airline incurs the cost $\alpha F < F$ (that is, $\alpha < 1$). Under these assumptions, we compute the total cost of a competitor k $(k = 2,3,\cdots,m+1)$ as:

$$C^k = cq_{HL}^k + \alpha F \text{ for } k = 2,3,\ldots,m+1, \tag{4}$$

where q_{HL}^k is the number of passengers using the flights of k for Route HL. For Airline 1, however, the total cost varies with its network configuration, $\boldsymbol{\delta}$. Specifically, the total cost of Airline 1 is written as the function of $\boldsymbol{\delta}$: namely,

$$C^1(\boldsymbol{\delta}) = \delta_{HL} c\gamma(\boldsymbol{\delta}) q_{HL}^1 + \delta_{HS} c\left(q_{HS}^1 + l(\boldsymbol{\delta}) q_{LS}^1\right) + F\left(\alpha\delta_{HL} + \sum_{r \neq HL} \delta_r\right), \tag{5}$$

where q_r^1 is the number of passengers on boarding Airline 1's flights along Route r. In Eq. (5), note that $\gamma(\boldsymbol{\delta}) = \delta_{HS} + (1 - \delta_{HS})\gamma$ and $l(\boldsymbol{\delta}) = \delta_{LS} l + 2(1 - \delta_{LS})$.

In addition, in market HL, $m + 1$ airlines compete whereas other two markets are under the monopoly; hence,

$$Q_{HL} = \sum_{k=1}^{m+1} q_{HL}^k, \; Q_{HS} = q_{HS}^1, \text{ and } Q_{LS} = q_{LS}^1.$$

The inverse demand functions are rewritten as follows:

$$p_{HL}(Q_{HL}) = p_{HL}(\mathbf{q_{HL}}), \; p_{HS}(Q_{HS}) = p_{HS}(q_{HS}^1), \text{ and } p_{LS}(Q_{LS}) = p_{LS}(q_{LS}^1),$$

where $\mathbf{q_{HL}}$ represents the vector of the seats provided by $m + 1$ airlines. Using this expression, the profits are rewritten as:

$$\pi^1(\boldsymbol{\delta}, \mathbf{q^1}, \mathbf{q_{HL}^-}) = p_{HL}(Q_{HL}) q_{HL}^1 + \delta_{HS}\left[p_{HS}(Q_{HS}) q_{HS}^1 + p_{LS}(Q_{LS}) q_{LS}^1\right] - C^1(\boldsymbol{\delta}), \tag{6.1}$$

$$\pi^k(q_{HL}^k, \mathbf{q_{HL}^-}) = p_{HL}(Q_{HL}) q_{HL}^k - C^k. \tag{6.2}$$

where $\mathbf{q^1} = (q_{HL}^1, q_{HS}^1, q_{LS}^1)$ and $\mathbf{q_{HL}^-}$ represents the vector of seats served by competitors.[5] Summing Eqs. (3) and (6), the social surplus under the network $\boldsymbol{\delta}$ is computed as follows:

$$SS(\mathbf{Q}, \boldsymbol{\delta}) = CS_{HL}(Q_{HL}) + \delta_{HS} \sum_{r=HS,LS} CS_r(Q_r) + \pi^1(\boldsymbol{\delta}, \mathbf{q^1}, \mathbf{q_{HL}^-}) + \sum_{k=2}^{m+1} \pi^k(q_{HL}^k, \mathbf{q_{HL}^-}). \tag{7}$$

[5] In Eqs. (5) and (6.1), the network choice on Route HS affects the flight operating costs and the revenues from the monopoly markets. This reflects the fact such that, without the service along HS, Airline 1 cannot earn the profits from its monopoly markets.

3. The Equilibrium and the Optimal Network Configurations

This section deals with the problem how the competition among the airlines on a route affects the network airline's choice. Specifically, we first solve the game among the airlines, and derive the equilibrium network configuration. Afterwards, the optimal network configuration, which maximizes the social surplus, is determined. Finally, by comparing the equilibrium and the optimal configurations, we summarize the distortion of the network choice due to the competition. This section is organized as follows. Subsection 3.1 deals with the equilibrium network configuration while Subsection 3.2 focuses on the optimal network configuration. This subsection also reports the inefficiency of the equilibrium network configuration.

3.1. The Equilibrium Network Configuration

We assume that the airlines compete in the Cournot fashion in the market of Route HL. Therefore, the airlines' problems are formulated as follows:

$$\max_{\mathbf{q^1}} \pi^1\left(\boldsymbol{\delta}, \mathbf{q^1}, \mathbf{q}_{\mathbf{HL}}^{-}\right), \tag{8.1}$$

$$\max_{q_{HL}^k} \pi^k\left(q_{HL}^k, \mathbf{q}_{\mathbf{HL}}^{-}\right) \text{ for } k = 2,3,\dots,m+1. \tag{8.2}$$

Solving the problems of (8), the first order conditions are:

$$\frac{\partial \pi^k\left(q_{HL}^k, \mathbf{q}_{\mathbf{HL}}^{-}\right)}{\partial q_{HL}^k} = 1 - c - \frac{2q_{HL}^k + \sum_{j\neq k} q_{HL}^j}{1+n_L} = 0, \tag{9.1}$$

$$\frac{\partial \pi^1\left(\boldsymbol{\delta}, \mathbf{q}^1, \mathbf{q}_{\mathbf{HL}}^{-}\right)}{\partial q_{HL}^1} = 1 - c\left[\gamma\left(1-\delta_{HS}\right)+\delta_{HS}\right] - \frac{2q_{HL}^1 + \sum_{j\neq 1} q_{HL}^j}{1+n_L} = 0, \tag{9.2}$$

$$\frac{\partial \pi^1\left(\boldsymbol{\delta}, \mathbf{q}^1, \mathbf{q}_{\mathbf{HL}}^{-}\right)}{\partial q_{HS}^1} = \delta_{HS}\left(1 - c - \frac{2q_{HS}^1}{1+n_S}\right) = 0, \tag{9.3}$$

$$\frac{\partial \pi^1\left(\boldsymbol{\delta}, \mathbf{q}^1, \mathbf{q}_{\mathbf{HL}}^{-}\right)}{\partial q_{LS}^1} = \delta_{HS}\left[1 - c\left(\delta_{LS} l + 2\left(1-\delta_{LS}\right)\right) - \frac{2q_{LS}^1}{n_L + n_S}\right] = 0. \tag{9.4}$$

First, by applying the assumption such that m competitors are symmetric, Eqs. (9.1) and (9.2) are solved as:

$$q_{HL}^{1*}\left(\boldsymbol{\delta}\right) = \frac{\left(1+n_L\right)\left[1 - c\left(\gamma\left(\boldsymbol{\delta}\right)\left(1+m\right) - m\right)\right]}{2+m}, \tag{10.1}$$

$$q_{HL}^{k*}\left(\boldsymbol{\delta}\right) = \frac{\left(1+n_L\right)\left[1 - c\left(2\gamma\left(\boldsymbol{\delta}\right) - 1\right)\right]}{2+m}. \tag{10.2}$$

From Eqs. (9.3) and (9.4), the seats for the two monopoly routes are computed as:[6]

$$q_{HS}^{1*}\left(\boldsymbol{\delta}\right) = \frac{\left(1+n_S\right)\left(1-c\right)}{2}, \tag{11.1}$$

$$q_{LS}^{1*}\left(\boldsymbol{\delta}\right) = \frac{\left(n_L + n_S\right)\left(1 - cl\left(\boldsymbol{\delta}\right)\right)}{2}. \tag{11.2}$$

Plugging Eqs. (9.1), (10.1), and (10.2) into Eqs. (6), the airlines' profits are derived as:[7]

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[6] Eq. (11.2) indicates that we implicitly assume that all the passengers for Routes HS and LS utilize the Airline 1's flight. Appendix A summarizes the set of the parameter values in which this is the case.

[7] The details of Airline 1's profits are summarized in Appendix B.

$$\pi^{1*}(\boldsymbol{\delta}) = \pi^{1}(\boldsymbol{\delta}, \mathbf{q}^{1*}, \mathbf{q}_{\mathbf{HL}}^{-*}) = \sum_r \delta_r \left[P_r(Q_r^*(\boldsymbol{\delta})) - c\gamma(\boldsymbol{\delta}) l_r(\boldsymbol{\delta}) \right] q_r^{1*}(\boldsymbol{\delta}) - F\left(\alpha\delta_{HL} + \sum_{r \neq HL} \delta_r \right), \quad (12)$$

$$\pi^{k*}(\boldsymbol{\delta}) = \pi^{k}(q_{HL}^{k*}, \mathbf{q}_{\mathbf{HL}}^{-*}) = \frac{(1+n_L)\left[1 - c(2\gamma(\boldsymbol{\delta}) - 1)\right]^2}{(2+m)^2} - \alpha F, \quad (13)$$

where

$$Q_{HL}^*(\boldsymbol{\delta}) = q_{HL}^{1*}(\boldsymbol{\delta}) + m q_{HL}^{k*}(\boldsymbol{\delta}) = \frac{(1+n_L)\left[(1+m) - c\left[\gamma(\boldsymbol{\delta})(1+3m) - 2m\right]\right]}{2+m}, \quad (14.1)$$

$$Q_r^*(\boldsymbol{\delta}) = q_r^{1*}(\boldsymbol{\delta}) \text{ for } r = HS, LS. \quad (14.2)$$

Also, note that, in Eq. (12), $l_r(\boldsymbol{\delta})$ is defined as:

$$l_{HL}(\boldsymbol{\delta}) = l_{HS}(\boldsymbol{\delta}) = 1 \text{ and } l_{LS}(\boldsymbol{\delta}) = \delta_{LS} l + 2(1 - \delta_{LS}).$$

In comparison of Eqs. (12), Airline 1 chooses its network configuration to maximize its profit, $\pi^{1*}(\boldsymbol{\delta})$.[8] Let us denote by $\boldsymbol{\delta}^*$ the equilibrium network configuration, and then it is derived from the following problem:

$$\boldsymbol{\delta}^* = \arg\max_{\boldsymbol{\delta}} \pi^{1*}(\boldsymbol{\delta}). \quad (15)$$

By solving Eq. (15), Proposition 1 summarizes the equilibrium network configuration.

Proposition 1

The equilibrium network configuration, $\boldsymbol{\delta}^*$*, is characterized by:*

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[8] We consider the situation where all the airlines earn the positive profits from Route HL. Otherwise, once ceasing the service along Route HS, Airline 1 must stop the service provision to HL since with a single route, Airline 1 has the cost disadvantage against its competitors. Appendix A shows the set of parameter values in which all the airlines earn the positive profits from HL.

$$\boldsymbol{\delta}^{*}=\begin{cases}(1,0,0) & \text{if } F>\bar{F}^{*},\\ (1,1,0) & \text{if } \bar{F}^{*}\geq F\geq \tilde{F}^{*},\\ (1,1,1) & \text{if } \tilde{F}^{*}>F,\end{cases} \tag{16}$$

where

$$\tilde{F}^{*}\equiv\frac{c\left(n_L+n_S\right)\left(2-l\right)\left[2-c\left(2+l\right)\right]}{4}, \tag{17.1}$$

$$\bar{F}^{*}\equiv\frac{c\left(1+n_L\right)\left(\gamma-1\right)\left[\left(2-m\right)-c\left(\left(1+\gamma\right)\left(1-2m^2\right)+m\left(4m-\gamma\right)\right)\right]}{\left(2+m\right)^2}+\frac{\left(1+n_S\right)\left(1-c\right)^2}{4}+\frac{\left(n_L+n_S\right)\left(1-2c\right)^2}{4}. \tag{17.2}$$

Proof: see Appendix B.

Proposition 1 shows that as the fixed cost increases, the equilibrium network configuration changes from the point-to-point to the single route via the hub-spoke network. The thresholds in Eqs. (17) show the Airline 1's tradeoff. In case of $\tilde{F}^{*}$, Airline 1 chooses the point-to-point if the fixed cost is smaller than the additional flight operating cost for connecting passengers.[9] In case of $\bar{F}^{*}$, as in Eq. (17.2), in contrast, Airline 1 serves to the two routes, HL and HS, if the fixed cost is smaller than the gains from the direct flight operations along the two routes. The gains from the two-route operation is consisted from the two components. In Eq. (17.2), the last two terms of the RHS capture the profits from the two markets, HS and LS. The first term

[9] As in Eq. (17.1), the threshold $\tilde{F}^{*}$ takes the negative sign if $l>2$. This indicates that if the distance between Airports L and S is larger than the distance between L and S via H, Airline 1 never chooses the point-to-point as its network configuration.

represents the cost reduction in the flight operation along Route HL since, in our setup, the multiple-route operation generates the economies of scope.

Observing the thresholds (17.1) and (17.2), $\tilde{F}^*$ is independent from the degrees of the competition, m, and of the economies of scope, γ, while these two parameters affect $\bar{F}^*$. That is, both the degrees of the competition and the economies of scope affect Airline 1's choice to maintain the direct flight service to Route HS. To confirm the effects of these two parameters, we state Proposition 2.

Proposition 2

i) As the economies of scope, γ, becomes more significant, Airline 1 has a stronger incentive to provide the direct flight service to Route HS; namely, $\partial\bar{F}^*/\partial\gamma > 0$.

ii) As the competition in Route HL becomes tougher, Airline 1 ceases the direct flight service more easily; namely, $\partial\bar{F}^*/\partial m < 0$.

Proof: Differentiating Eq. (17.2) with respect to γ and m,

$$\frac{\partial\bar{F}^*}{\partial\gamma} = \frac{c(1+n_L)\left[(2-m)-c\left((1+2\gamma)(1-2m^2)+m(4m-2\gamma)\right)\right]}{(2+m)^2} > 0,$$

$$\frac{\partial\bar{F}^*}{\partial m} = -\frac{m\bar{F}^*}{(m+1)(m+2)} - \frac{c^2(1+n_L)(\gamma-1)^2(m+1)}{(2+m)^2} < 0.$$

QED

From Proposition 2, as the economies of scope increases, Airline 1 becomes more willing to serve to Route HS. This is because providing the service to HS relaxes Airline 1's cost disadvantage in market HL against its competitors. The intense competition, however, makes Airline 1 stop serving to HS more easily because the gain from maintaining Route HS becomes less significant.

3.2. The Optimal Network Configuration

The social planner maximizes the social surplus, $SS(\boldsymbol{\delta})$, by determining the seats provided along each Route r, Q_r, and the network configuration, $\boldsymbol{\delta}$. The social planner can utilize the efficient technology when providing the flight service; namely, the marginal operating cost for each Route r is given by $cl_r(\boldsymbol{\delta})$. Using Eqs. (2) and (3), the social surplus under the network $\boldsymbol{\delta}$ is computed as:[10]

$$\begin{aligned} SS^O(\mathbf{Q},\boldsymbol{\delta}) = \delta_{HL}\left[CS_{HL}(Q_{HL}) + \left(P_{HL}(Q_{HL}) - c\right)Q_{HL} - \alpha F\right] \\ + \delta_{HS}\sum_{r\neq HL}\left[CS_r(Q_r) + \left(P_r(Q_r) - cl_r(\boldsymbol{\delta})\right)Q_r - F\right], \end{aligned} \tag{18}$$

where $\mathbf{Q} = (Q_{HL}, Q_{HS}, Q_{LS})$.

When determining the seats for each route, the social planner solves the following problem:

$$\max_{\mathbf{Q}} SS^O(\mathbf{Q},\boldsymbol{\delta}).$$

Solving this problem, the seats served for Route r at the optimum is computed as:

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[10] Since the multiple airline operation augments the fixed cost for the route operation, the social planner allows a single airline operation for each route.

$$\mathbf{Q^O}(\boldsymbol{\delta}) = \left((1+n_L)(1-c), (1+n_S)(1-c), (n_L+n_S)(1-cl(\boldsymbol{\delta}))\right). \tag{19}$$

Substituting Eq. (19) into Eq. (18), the social surplus is written as the function of $\boldsymbol{\delta}$: that is, $SS^O(\boldsymbol{\delta}) = SS^O(\mathbf{Q^O}(\boldsymbol{\delta}), \boldsymbol{\delta})$. The optimal network configuration, $\boldsymbol{\delta}^\mathbf{O}$, is derived as the solution to the following problem:

$$\boldsymbol{\delta}^\mathbf{O} = \arg\max_{\boldsymbol{\delta}} SS^O(\boldsymbol{\delta}). \tag{20}$$

Proposition 3 summarizes the solution of (20), $\boldsymbol{\delta}^\mathbf{O}$:

Proposition 3

The optimal network configuration, $\boldsymbol{\delta}^\mathbf{O}$*, is characterized by:*

$$\boldsymbol{\delta}^\mathbf{O} = \begin{cases} (1,0,0) \text{ if } F > \bar{F}^O, \\ (1,1,0) \text{ if } \bar{F}^O \geq F \geq \tilde{F}^O, \\ (1,1,1) \text{ if } \tilde{F}^O > F, \end{cases} \tag{21}$$

where

$$\tilde{F}^O \equiv \frac{c(n_L+n_S)(2-l)\left[2-c(2+l)\right]}{2}, \tag{22.1}$$

$$\bar{F}^O \equiv \frac{(1+n_S)(1-c)^2}{2} + \frac{(n_L+n_S)(1-2c)^2}{2}. \tag{22.2}$$

Proof: see Appendix B.

The optimal configuration, $\boldsymbol{\delta}^\mathbf{O}$, is qualitatively similar to the equilibrium, $\boldsymbol{\delta}^*$: namely, the network changes from the point-to-point to the single route via the hub-spoke as the fixed cost, F, increases.[11]

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[11] Observing Eq. (22.1), it is easily confirmed that, when Airports L and S is sufficiently distant

By comparing the thresholds in Propositions 1 and 3, the inefficiencies of the equilibrium network configurations are summarized in Proposition 4.

Proposition 4

By comparing with the optimal network configuration, Airline 1 *ceases the direct flight service along Routes* HS *and* LS *more easily.*

Proof: By comparing the thresholds, $\tilde{F}^*$ and $\tilde{F}^O$,

$$\tilde{F}^* - \tilde{F}^O = -\frac{c(n_L + n_S)(2-l)[2-c(2+l)]}{4} < 0.$$

This indicates that, for $\tilde{F}^* < F < \tilde{F}^O$, Airline 1 stops providing the direct flight service for Route LS even though the optimal network configuration is the point-to-point. For $\bar{F}^*$ and $\bar{F}^O$,

$$\bar{F}^* - \bar{F}^O = \frac{c(1+n_L)(\gamma-1)(m+1)\left[2-c\left[(m+1)(\gamma+1)-2m\right]\right]}{(2+m)^2} - \frac{(1+n_S)(1-c)^2}{4} - \frac{(n_L+n_S)(1-2c)^2}{4}.$$

The first term captures the Airline 1's loss in Route HL whereas the last two terms capture the difference in the Airline 1's profit and the consumers' gains in other two routes. Rearranging this, we have $\bar{F}^* < \bar{F}^O$. For $\bar{F}^* < F < \bar{F}^O$, although the optimal network is the hub-spoke, Airline 1 chooses to provide the direct flight service to the

(namely, $l > 2$), $\tilde{F}^O < 0$. This implies that, for $l > 2$, the point-to-point network is less efficient than other two networks.

single route, HL.

QED

The inefficiencies of the Airline 1's network choice is generated from the following two sources. First, due to the market power of Airline 1, the seats provided in markets HS and LS become too small relative to the optimum; therefore, Airline 1 receives the relatively small gains in the two markets compared to those the social planner receives. Furthermore, when determining the network configuration, Airline 1 solely focuses on its profit whereas the planner considers the consumers' gains as well as the airlines' profits. Thus, compared to the optimum, Airline 1 ceases the direct flight service for thin demand routes more easily than the socially desired level.

4. Direct Regulation vs. Universal Service Fees

In Section 3, we have shown that, at the equilibrium, Airline 1 stops the direct flight service to the thin markets even when the service provision is efficient. To correct the Airline 1's choice, this section introduces the two policy instruments, the direct regulation and the universal service fee. Under the direct regulation, taking the airlines' choices on the seats into account, from the efficiency perspective, the government forces Airline 1 to keep the direct flight service along the thin demand routes. In case of the universal service fee, the fees are collected on a per passenger basis, and the fee revenue are redistributed among the routes. This implies that passengers on some routes just pay the fees whereas passengers on other routes receive the subsidy. Hence, in this section, under the fee scheme, the government chooses the fee net of the subsidy for each route to maximize the social surplus whereas Airline 1 determines its network configuration.

The rest of this section is organized as follows: first, Subsection 4.1 describes the direct regulation. Subsection 4.2 reports the network choice by Airline 1 under the fee scheme by tracking back the sequence of decisions. Specifically, in this subsection, we first report the results of the competition, and explain the fee scheme under the three alternative network structures. Finally, Subsection 4.3 addresses the question under what circumstance the fee scheme enhances the economic welfare than the direct regulation does.

4.1. The Direct Regulation

Due to the imperfect competition, Proposition 4 reports the inefficiencies of the equilibrium network configuration. In this subsection, we examine the regulated network configuration. Specifically, the government determines this configuration in order to maximize the social surplus whereas airlines choose the seats served to each route. Substituting Eqs. (14) into (7), the social surplus under the network $\boldsymbol{\delta}$ is computed as $SS(\boldsymbol{\delta}) = SS(\mathbf{Q}^*(\boldsymbol{\delta}), \boldsymbol{\delta})$.[12] The regulated network configuration, $\boldsymbol{\delta}^{\mathbf{R}}$, is obtained by solving the following problem:

$$\boldsymbol{\delta}^{\mathbf{R}} = \arg\max_{\boldsymbol{\delta}} SS(\boldsymbol{\delta}). \tag{23}$$

By solving the problem (23), the regulated network configuration, $\boldsymbol{\delta}^{\mathbf{R}}$, is derived as in Proposition 5.

Proposition 5

The regulated network configuration, $\boldsymbol{\delta}^{\mathbf{R}}$*, is characterized by:*

$$\boldsymbol{\delta}^{\mathbf{R}} = \begin{cases} (1,0,0) & \text{if } F > \bar{F}^R, \\ (1,1,0) & \text{if } \bar{F}^R \ge F \ge \tilde{F}^R, \\ (1,1,1) & \text{if } \tilde{F}^R > F, \end{cases} \tag{24}$$

where

$$\tilde{F}^R \equiv \frac{3c(n_L + n_S)(2-l)\left[2 - c(2+l)\right]}{8}, \tag{25.1}$$

$$\bar{F}^R \equiv \frac{c(1+n_L)(\gamma-1)\left[3\left(2 - c(1+\gamma)\left(1+2m^2\right)\right) + 4m\left(1 + c(\gamma-2)\left(1+2m^2\right) - m\right)\right]}{2(2+m)^2} + \frac{c^2m^2(1+n_L)(\gamma-1)^2}{2(2+m)^2} + \frac{3(1+n_S)(1-c)^2}{8} + \frac{3(n_L+n_S)(1-2c)^2}{8}. \tag{25.2}$$

Proof: see Appendix C.

[12] The detailed expressions are in Appendix C.

The regulated configuration, $\boldsymbol{\delta}^{\mathbf{R}}$, resembles to other two network configurations, the equilibrium, $\boldsymbol{\delta}^{*}$, and the optimum, $\boldsymbol{\delta}^{\mathbf{O}}$: namely, the network changes from the point-to-point to the single route via the hub-spoke as the fixed cost, F, increases.[13] Under the regulated network, the social benefit of keeping a route includes the consumer's surplus and the competitors' profits as well as the Airline 1's profit.

Focusing on Eq. (25.2), which shows the social tradeoff of keeping the hub-spoke network, the social gain from keeping the hub-spoke network is decomposed into the two parts. Namely, the last two terms capture the social surpluses of Routes HS and LS while the first term represent the net gain of Route HL. As explained above, the net gain is generated from the economies of scope through maintaining the service provision along Route HS; hence, Airline 1 can earn the larger profits from HL. In addition, without Airline 1's disadvantage, the competition in HL becomes more intense, passengers traveling between H and L can enjoy the lower airfare. In contrast, when Airline 1 serves to HS, the competitors have no advantage against Airline 1; consequently, they receive the loss compared to the case where Airline 1 chooses the single route. In sum, however, the gain dominates the loss, and the first term of the RHS in Eq. (25.2) takes the positive sign.

[13] Similar to other two network configurations, $\boldsymbol{\delta}^{*}$ and $\boldsymbol{\delta}^{\mathbf{O}}$, Eq. (25.1) becomes negative if $l > 2$. This implies that the government never forces Airline 1 to serve the direct flights to Route LS when the distance between L and S is sufficiently large.

4.2. The Universal Service Fee

The fee is imposed on the airlines on a per passenger basis, and it is imposed on the airlines. The fee revenue is redistributed among the three routes to maximize the social surplus. In other words, the government faces the balanced budget constraint, and the government's problem is formulated as maximizing the social surplus by determining the fee net of the subsidy for each route. Let us denote by τ_r the fee net of the subsidy to a passenger traveling Route r.[14] Then, the airlines' costs are rewritten as:

$$C^k(\boldsymbol{\tau}) = (c + \tau_{HL}) q^k_{HL} + \alpha F \text{ for } k = 2, 3, \ldots, m+1, \tag{26.1}$$

$$C^1(\boldsymbol{\delta};\boldsymbol{\tau}) = c\left[\gamma(\boldsymbol{\delta}) q^1_{HL} + \delta_{HS}\left(q^1_{HS} + l(\boldsymbol{\delta}) q^1_{LS}\right)\right] + \sum_r \tau_r \delta_r q^1_r + F\left(\alpha\delta_{HL} + \sum_{r \neq HL} \delta_r\right). \tag{26.2}$$

By using Eqs. (2) and (26), the profits of the airlines are written as the function of $\boldsymbol{\tau}$:

$$\pi^1\left(\boldsymbol{\delta}, \mathbf{q^1}, \mathbf{q^-_{HL}}; \boldsymbol{\tau}\right) = p_{HL}(Q_{HL}) q^1_{HL} + \delta_{HS}\left[p_{HS}(Q_{HS}) q^1_{HS} + p_{LS}(Q_{LS}) q^1_{LS}\right] - C^1(\boldsymbol{\delta};\boldsymbol{\tau}),$$

$$\pi^k\left(q^k_{HL}, \mathbf{q^-_{HL}}; \boldsymbol{\tau}\right) = p_{HL}(Q_{HL}) q^k_{HL} - C^k(\boldsymbol{\tau}).$$

The airlines solve the following profit maximization problem:

$$\max_{\mathbf{q^1}} \pi^1\left(\boldsymbol{\delta}, \mathbf{q^1}, \mathbf{q^-_{HL}}; \boldsymbol{\tau}\right),$$

$$\max_{q^k_{HL}} \pi^k\left(q^k_{HL}, \mathbf{q^-_{HL}}; \boldsymbol{\tau}\right) \text{ for } k = 2, 3, \ldots, m+1.$$

The solutions of these problems are:

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[14] The fee for each route may take the positive or the negative sign. The positive fee implies the tax is levied on the passenger traveling the route while the passengers receive the subsidy if the fee is negative.

$$q_{HL}^{1*}(\boldsymbol{\delta};\boldsymbol{\tau}) = \frac{(1+n_L)\left[1-c(\gamma(\boldsymbol{\delta})(1+m)-m)-\tau_{HL}\right]}{2+m}, \tag{27.1}$$

$$q_{HL}^{k*}(\boldsymbol{\delta};\boldsymbol{\tau}) = \frac{(1+n_L)\left[1-c(2\gamma(\boldsymbol{\delta})-1)-\tau_{HL}\right]}{2+m}, \tag{27.2}$$

$$q_{HS}^{1*}(\boldsymbol{\delta};\boldsymbol{\tau}) = \frac{(1+n_S)(1-c-\tau_{HS})}{2}, \tag{27.3}$$

$$q_{LS}^{1*}(\boldsymbol{\delta};\boldsymbol{\tau}) = \frac{(n_L+n_S)(1-cl(\boldsymbol{\delta})-\tau_{LS})}{2}. \tag{27.4}$$

Substituting Eqs. (27) into (7), the social surplus under the network $\boldsymbol{\delta}$ is written as the function of the fees as well as the network choice: [15] that is, $SS(\boldsymbol{\tau};\boldsymbol{\delta}) = SS(\mathbf{Q}^*(\boldsymbol{\delta};\boldsymbol{\tau}),\boldsymbol{\delta})$.

Using this, the government's problem is formulated as:

$$\max_{\boldsymbol{\tau}} SS(\boldsymbol{\tau};\boldsymbol{\delta}) \text{ subject to } \sum_r \tau_r Q_r^*(\boldsymbol{\delta};\boldsymbol{\tau}) = 0.$$

From the balanced budget constraint, it is obvious that, in case of $\boldsymbol{\delta} = (1,0,0)$, $\tau_{HL} = 0$.

For the other two networks, we derive the first order conditions as follows:

$$\tau_{HL}: \left[\frac{Q_{HL}^*}{2} + \frac{1+(2m+1)(p_{HL}-2c)}{2}\frac{\partial Q_{HL}^*}{\partial p_{HL}}\right]\frac{\partial p_{HL}}{\partial \tau_{HL}} + \lambda\left[\tau_{HL}\frac{\partial Q_{HL}^*}{\partial p_{HL}}\frac{\partial p_{HL}}{\partial \tau_{HL}} + Q_{HL}^*\right] = 0, \tag{28.1}$$

$$\tau_{HS}: \left[\frac{Q_{HS}^*}{2} + \frac{1+p_{HS}-2c}{2}\frac{\partial Q_{HS}^*}{\partial p_{HS}}\right]\frac{\partial p_{HS}}{\partial \tau_{HS}} + \lambda\left[\tau_{HS}\frac{\partial Q_{HS}^*}{\partial p_{HS}}\frac{\partial p_{HS}}{\partial \tau_{HS}} + Q_{HS}^*\right] = 0, \tag{28.2}$$

$$\tau_{LS}: \left[\frac{Q_{LS}^*}{2} + \frac{1+p_{LS}-2cl(\boldsymbol{\delta})}{2}\frac{\partial Q_{LS}^*}{\partial p_{LS}}\right]\frac{\partial p_{LS}}{\partial \tau_{LS}} + \lambda\left[\tau_{LS}\frac{\partial Q_{LS}^*}{\partial p_{LS}}\frac{\partial p_{LS}}{\partial \tau_{LS}} + Q_{LS}^*\right] = 0, \tag{28.3}$$

where λ represents the Lagrange multiplier for the balanced budget constraint. Since it

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[15] Given the Airline 1's network choice, $\boldsymbol{\delta}$, the government chooses the levels of the fees for each route to maximize the social surplus under the balanced budget constraint. Hence, the social surplus is computed as the sum of the consumer's surplus and the airlines' profits.

is difficult to derive the fees explicitly, we derive the pricing rules for the three routes from Eqs. (28):

$$\tau_{HL}^{T} = -\frac{p_{HL}^{T}}{\varepsilon_{HL}^{T}}\left(\frac{1}{2\lambda}+\frac{m+2}{m+1}\right)-\frac{1+p_{HL}^{T}-2c}{2\lambda}, \tag{29.1}$$

$$\tau_{HS}^{T} = -\frac{p_{HS}^{T}}{\varepsilon_{HS}^{T}}\left(\frac{1}{2\lambda}+2\right)-\frac{1+p_{HS}-2c}{2\lambda}, \tag{29.2}$$

$$\tau_{LS}^{T} = -\frac{p_{LS}^{T}}{\varepsilon_{LS}^{T}}\left(\frac{1}{2\lambda}+2\right)-\frac{1+p_{LS}^{T}-2cl(\boldsymbol{\delta})}{2\lambda}, \tag{29.3}$$

where ε_r^T measures the price elasticity of the trip demand for Route r. In addition, since the no fee is applied under the single route, $\boldsymbol{\delta}=(1,0,0)$, Eqs. (29) are independent from the economies of scope, γ.

From the balanced budget constraint, passengers traveling some routes receive the subsidy while the positive fee is levied on the other passengers. Observing Eqs. (29), we can easily confirm that the price elasticity is the key factor when determining the sign. This is summarized in Proposition 6.

Proposition 6

As the demand for Route r becomes more elastic, the fee for Route r takes the negative sign.

Proof: In Eqs. (29), since $\varepsilon_r < 0$, the first terms of the RHS always take the positive sign while the second terms are negative. Therefore, as $|\varepsilon_r|$ increases, the first term in the absolute value decreases. Hence, the elastic demand leads to the negative fee.

QED

Since Routes HS and LS are under the monopoly whereas Route HL is under the competition, the demands for Routes HS and LS are more elastic than the one for HL. This implies that the positive fee is levied on the competitive market, and the travelers in the monopoly markets are subsidized by using the fee revenue.

Although the intuition is quite clear, it is difficult to solve Eqs. (28) explicitly. Let us denote by $\tau_r^T(\boldsymbol{\delta})$ the solutions of Eqs. (28); then, the profits of Airline 1 under the three alternative networks, $\pi^{1T}(\boldsymbol{\delta})$, are computed as:

$$\pi^{1T}(\boldsymbol{\delta}) = \sum_r \delta_r \left[\left(p_r\left(\boldsymbol{\delta};\boldsymbol{\tau}^{\mathbf{T}}(\boldsymbol{\delta})\right) - c\gamma(\boldsymbol{\delta}) l_r(\boldsymbol{\delta}) - \tau_r^T(\boldsymbol{\delta}) \right) q_r^{1*}\left(\boldsymbol{\delta};\boldsymbol{\tau}^{\mathbf{T}}(\boldsymbol{\delta})\right) \right] - F\left(\alpha\delta_{HL} + \sum_{r \neq HL} \delta_r \right). \tag{30}$$

By using Eq. (30), the equilibrium network configuration under the fee scheme, $\boldsymbol{\delta}^{\mathbf{T}}$, is derived from the following problem:

$$\boldsymbol{\delta}^{\mathbf{T}} = \arg\max_{\boldsymbol{\delta}} \pi^{1T}(\boldsymbol{\delta}).$$

To derive $\boldsymbol{\delta}^{\mathbf{T}}$, we compare the profits under the three alternative networks, and obtain the thresholds, $\tilde{F}^T$ and $\bar{F}^T$. Similar to the thresholds of other three network configurations, at $F = \tilde{F}^T$, Airline 1 is indifferent between the point-to-point and the hub-spoke. For $F > \tilde{F}^T$, the hub-spoke maximizes the Airline 1's profit while for $F <$

$\tilde{F}^T$, Airline 1 prefers the point-to-point. At $F = \bar{F}^T$, the profits under the hub-spoke and the single route are identical. For $F > \bar{F}^T$, the profit under the single route is the largest whereas Airline 1 chooses the hub-spoke for $F < \bar{F}^T$.

Through the numerical simulations, Figure 3 summarizes the effects on the thresholds, $\tilde{F}^T$ and $\bar{F}^T$, of the degrees of the competition, m, and the economies of scope, γ. The upper side of Figure 3 shows that both $\tilde{F}^T$ and $\bar{F}^T$ increases as the degree of the competition becomes more intense. This is interpreted as follows. As in Proposition 6, by operating the direct flight service along Routes HS and LS, Airline 1 receives the subsidy from the competitors. Furthermore, since the more intense competition make the demand for HL trip more inelastic, the subsidy increases as the competitors increase; consequently, Airline 1 has more incentives to keep the service to the thin demand routes.

<<Figure 3: ABOUT HERE>>

The lower side of Figure 3 reports the effect of the economies of scope on the Airline 1's network choice. The economies of scope are measured by γ, which reflect the marginal cost increase due to ceasing the service to the multiple routes. It is shown that although the fee scheme expands the domains of the point-to-point and the hub-spoke, the marginal effect of the economies of scope on the thresholds is equivalent to the one on the equilibrium thresholds. Therefore, as the degree of the economies of scope increases, the domain of the hub-spoke expands whereas that of the point-to-point remains constant. In other words, as in Proposition 2, the economies of scope motivate Airline 1 to sustain the service provision along HS whereas they have no impact on the direct flight service provision along LS.

4.3. The Welfare Effects of the Two Policies

To evaluate the welfare effects of the two alternative policies, Figures 4 and 5 compare the thresholds of the four alternative network configurations. Figure 4 summarize the effect of the degree of the competition on the thresholds. It shows that in case of the hub-spoke network, for $m \geq 3$, $\bar{F}^R < \bar{F}^T < \bar{F}^O$. That is, for $\bar{F}^R < F < \bar{F}^T$, the fee makes Airline 1 sustain the service for HS whereas this service is allowed to abolish under the direct regulation. Since, for this domain, the optimal network is the hub-spoke, compared to the direct regulation, the fee scheme makes Airline 1 keep the service along HS more efficiently. In contrast, with respect to the direct flight service along LS, $\tilde{F}^T < \tilde{F}^R < \tilde{F}^O$. Namely, for $\tilde{F}^T < F < \tilde{F}^R$, the fee scheme has no impact on the network choice by Airline 1 while the direct regulation succeeds in keeping the service for LS. Since, for this domain, the point-to-point is efficient, the direct regulation is more efficient than the fee scheme.

<<Figure 4: ABOUT HERE>>

Figure 5 shows the effects of the economies of scope on the thresholds. As in the figures, both $\bar{F}^R$ and $\bar{F}^T$ increase as the economies of scope, γ, become more significant whereas $\tilde{F}^R$ and $\tilde{F}^T$ are constant. It is shown that, independent from both the degree of the competition and the economies of scope, $\tilde{F}^T < \tilde{F}^R < \tilde{F}^O$ always holds. That is, when Airline 1 has already formed the point-to-point, between the two alternative policies, the direct regulation is superior to the fee scheme when maintaining the direct flight service between Airports L and S. In contrast, in comparison of $\bar{F}^R$ and $\bar{F}^T$, the efficient policy tool depends on the degree of the competition. Namely, the direct regulation is socially preferred under the less competitive situation while the fee scheme sustains the service along Route HS more efficiently under the intense competition. In other words, the ranking between the two policies is independent from the economies of scope. These results indicate that the fee scheme assures the efficient outcome when Airline 1 faces the intense competition in the thick demand route and it has already formed the hub-spoke network.

5. Conclusion

This paper develops a three-airport model in which a full-service airline can determine its network configuration. Furthermore, the degree of the competition differs among the routes; namely, the full-service airline faces the competition in the thick demand route while other two routes are under the monopoly by the full-service airline. By using this model, we address the problems such as: i) how the competition affects the full-service airline's network; ii) by comparing the direct regulation and the fee scheme, which policy enhances the economic welfare. On the first problem, when the full-service airline forms the hub-spoke network, the competition makes the airline cease the direct flight service along the thin demand route more easily. Furthermore, the network without any intervention by the government is the least efficient; therefore, it is necessary to introduce some policy intervention.

With respect to the policy intervention, we consider the two alternative policies, the direct regulation and the fee scheme. The efficiency gain of the two policies differs with the airline's network choice. It is shown that, when the airline forms the point-to-point, the direct regulation achieves the higher efficiency gain than the fee scheme does. In contrast, the fee scheme generates the larger efficiency gain if the airline forms the hub-spoke network. This result is attributed to the difference in the effect of the competition on the airline's network choice. In case of the point-to-point, the competition in the thick market does not affect the network choice while, in case of the hub-spoke, the intense competition increases the subsidy to the full-service airline; consequently, under the hub-spoke network, the fee scheme is socially preferred to the direct regulation.

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Appendix A: Ranges of Parameter Values

The airfares for the three routes are computed as:

$$p_{HL}^{*}(\boldsymbol{\delta}) = P_{HL}\left(Q_{HL}^{*}(\boldsymbol{\delta})\right) = \frac{1+c\left[\gamma(\boldsymbol{\delta})(1+3m)-2m\right]}{2+m},$$

$$p_{HS}^{*}(\boldsymbol{\delta}) = P_{HS}\left(q_{HS}^{1*}(\boldsymbol{\delta})\right) = \frac{1+c}{2},$$

$$p_{LS}^{*}(\boldsymbol{\delta}) = P_{LS}\left(q_{LS}^{1*}(\boldsymbol{\delta})\right) = \frac{1+cl(\boldsymbol{\delta})}{2}.$$

The travelers of Routes HS and LS use the service provided by Airline 1 if:

$$p_{HS}^{*}(\boldsymbol{\delta}) = \frac{1+c}{2} \le p_{HL}^{*}(\boldsymbol{\delta}) + p_{LS}^{*}(\boldsymbol{\delta}) = \frac{1+cl(\boldsymbol{\delta})}{2} + \frac{1+c\left[\gamma(\boldsymbol{\delta})(1+3m)-2m\right]}{2+m}, \quad \text{(A.1.1)}$$

$$p_{LS}^{*}(\boldsymbol{\delta}) = \frac{1+cl(\boldsymbol{\delta})}{2} \le p_{HL}^{*}(\boldsymbol{\delta}) + p_{HS}^{*}(\boldsymbol{\delta}) = \frac{1+c\left[\gamma(\boldsymbol{\delta})(1+3m)-2m\right]}{2+m} + \frac{1+c}{2}. \quad \text{(A.1.2)}$$

Since the trip services for Routes HS and LS is not available if $\boldsymbol{\delta} = (1,0,0)$, we limit our focus to the cases where Airline 1 forms the hub-spoke, $\boldsymbol{\delta} = (1,1,0)$, or the point-to-point, $\boldsymbol{\delta} = (1,1,1)$. In such situation, Eqs. (A.1) are rewritten as:

$$p_{HS}^{*}(\boldsymbol{\delta}) = \frac{1+c}{2} \le p_{HL}^{*}(\boldsymbol{\delta}) + p_{LS}^{*}(\boldsymbol{\delta}) = \frac{(4+m)+c\left[l(\boldsymbol{\delta})(2+m)+2\right]}{2(2+m)}, \quad \text{(A.2.1)}$$

$$p_{LS}^{*}(\boldsymbol{\delta}) = \frac{1+cl(\boldsymbol{\delta})}{2} \le p_{HL}^{*}(\boldsymbol{\delta}) + p_{HS}^{*}(\boldsymbol{\delta}) = \frac{1+c}{2+m} + \frac{1+c}{2} = \frac{(4+m)(1+c)}{2(2+m)}. \quad \text{(A.2.2)}$$

Focusing on Eq. (A.2.1), since $l(\boldsymbol{\delta}) = \delta_{LS}l + 2(1-\delta_{LS}) \ge 1$, $p_{HS}^{*}(\boldsymbol{\delta}) \le p_{LS}^{*}(\boldsymbol{\delta})$; therefore, Eq. (A.2.1) is automatically satisfied. For Eq. (A.2.2), in cases of $\boldsymbol{\delta} = (1,1,1)$ and $\boldsymbol{\delta} = (1,1,0)$, the following conditions are met:

$$\frac{1+cl}{2} - \frac{(4+m)(1+c)}{2(2+m)} = \frac{c\left[l(2+m)-4+m\right]-2}{2(2+m)} \le 0 \Leftrightarrow l \le \bar{l} = \frac{2+c(4+m)}{c(2+m)}, \quad \text{(A.3.1)}$$

$$\frac{1+2c}{2}-\frac{(4+m)(1+c)}{2(2+m)}=\frac{3cm-2}{2(2+m)}\leq 0 \Leftrightarrow m\leq \bar{m}=\frac{2}{3c}. \quad \text{(A.3.2)}$$

In addition to Eqs. (A.3), to assure that Airline 1 can provide the service to Route HL, the following condition should be satisfied:

$$\pi^{1*}(1,0,0)=\frac{(1+n_L)\left[1-c\left(\gamma(1-2m)+2m\right)\right]\left[1-c\left(\gamma(1+m)-m\right)\right]}{(2+m)^2}-\alpha F\geq 0.$$

Solving this for F,

$$F\leq \bar{F}=\frac{(1+n_L)\left[1-c\left(\gamma(1-2m)+2m\right)\right]\left[1-c\left(\gamma(1+m)-m\right)\right]}{\alpha(2+m)^2}. \quad \text{(A.4)}$$

Furthermore, under the single route, the seats served by Airline 1 should be non-negative (that is, $q_{HL}^{1*}(1,0,0)\geq 0$), and the profit per seat should be non-negative (that is, $p_{HL}^{*}(1,0,0)-\gamma c\geq 0$). These conditions are formally written as:

$$q_{HL}^{1*}(1,0,0)\geq 0 \Leftrightarrow 1-c\left[\gamma(1+m)-m\right]\geq 0 \Leftrightarrow \gamma\leq\bar{\gamma}=\frac{1+cm}{c(1+m)}, \quad \text{(A.5.1)}$$

$$p_{HL}^{*}(1,0,0)-\gamma c\geq 0 \Leftrightarrow 1+c\left[\gamma(2m-1)-2m\right]\geq 0 \Leftrightarrow \gamma\geq\underline{\gamma}=\frac{2cm-1}{c(2m-1)}. \quad \text{(A.5.2)}$$

Summarizing these conditions, we state Lemma 1, which summarizes the range of parameter values:

Lemma 1

Travelers along Routes HS and LS utilize the service provided by Airline 1, and Airline 1 earns the non-negative profit when it chooses the single route if the parameters suffice the following relations:

$$l \leq \bar{l}, m \leq \bar{m}, F \leq \bar{F}, \text{ and } \underline{\gamma} \leq \gamma \leq \bar{\gamma}.$$

Appendix B: Proofs of Propositions in Section 3

First, the profits of Airline 1 under the three alternative networks are computed as:

$$\pi^{1*}(1,1,1) = \frac{(1+n_L)(1-c)^2}{(2+m)^2} + \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-cl)^2}{4} - F(2+\alpha), \quad \text{(B.1.1)}$$

$$\pi^{1*}(1,1,0) = \frac{(1+n_L)(1-c)^2}{(2+m)^2} + \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-2c)^2}{4} - F(1+\alpha), \quad \text{(B.1.2)}$$

$$\pi^{1*}(1,0,0) = \frac{(1+n_L)\left[1-c\left(\gamma(1-2m)+2m\right)\right]\left[1-c\left(\gamma(1+m)-m\right)\right]}{(2+m)^2} - \alpha F. \quad \text{(B.1.3)}$$

Comparing the profits of Airline 1, $\pi^{1*}(\boldsymbol{\delta})$, the equilibrium network configuration, $\boldsymbol{\delta}^*$, is summarized in Proposition 1:

Proposition 1

The equilibrium network configuration, $\boldsymbol{\delta}^*$*, is characterized by:*

$$\boldsymbol{\delta}^* = \begin{cases} (1,0,0) & \text{if } F > \bar{F}^*, \\ (1,1,0) & \text{if } \bar{F}^* \geq F \geq \tilde{F}^*, \\ (1,1,1) & \text{if } \tilde{F}^* > F, \end{cases} \quad \text{(16)}$$

where

$$\tilde{F}^* \equiv \frac{c(n_L+n_S)(2-l)\left[2-c(2+l)\right]}{4}, \quad \text{(17.1)}$$

$$\bar{F}^* \equiv \frac{c(1+n_L)(\gamma-1)\left[(2-m)-c\left((1+\gamma)(1-2m^2)+m(4m-\gamma)\right)\right]}{(2+m)^2} + \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-2c)^2}{4}. \quad \text{(17.2)}$$

Proof: By comparing the profits under the point-to-point and the hub-spoke, we obtain the following relation:

$$\pi^{1*}(1,1,1) > \pi^{1*}(1,1,0) \Leftrightarrow \frac{c(n_L+n_S)(2-l)[2-c(2+l)]}{4} - F > 0.$$

Solving this for F,

$$\pi^{1*}(1,1,1) > \pi^{1*}(1,1,0) \Leftrightarrow F < \tilde{F}^* \equiv \frac{c(n_L+n_S)(2-l)[2-c(2+l)]}{4}.$$

This implies that, for $F < \tilde{F}^*$, the point-to-point network maximizes the Airline 1's profit while for $F \geq \tilde{F}^*$, the hub-spoke becomes more profitable than the point-to-point.

In comparison of the profits under the hub-spoke and the single route, we have:

$$\pi^{1*}(1,1,0) > \pi^{1*}(1,0,0) \Leftrightarrow \frac{c(1+n_L)(\gamma-1)\left[(2-m)-c\left((1+\gamma)(1-2m^2)+m(4m-\gamma)\right)\right]}{(2+m)^2} + \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-2c)^2}{4} - F > 0.$$

Again, solving this for F,

$$\pi^{1*}(1,1,0) > \pi^{1*}(1,0,0) \Leftrightarrow F < \overline{F}^* \equiv \frac{c(1+n_L)(\gamma-1)\left[(2-m)-c\left((1+\gamma)(1-2m^2)+m(4m-\gamma)\right)\right]}{(2+m)^2} + \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-2c)^2}{4}.$$

For $F < \overline{F}^*$, Airline 1 chooses the hub-spoke network while, for $F \geq \overline{F}^*$, Airline solely provides the direct flight service to HS.

QED

To derive the optimal network configuration, the social surplus under the three alternative networks are computed as:

$$SS^O(1,1,1)=\frac{(1+n_L)(1-c)^2}{2}+\frac{(1+n_S)(1-c)^2}{2}+\frac{(n_L+n_S)(1-cl)^2}{2}-F(2+\alpha), \quad \text{(B.2.1)}$$

$$SS^O(1,1,0)=\frac{(1+n_L)(1-c)^2}{2}+\frac{(1+n_S)(1-c)^2}{2}+\frac{(n_L+n_S)(1-2c)^2}{2}-F(1+\alpha), \quad \text{(B.2.2)}$$

$$SS^O(1,0,0)=\frac{(1+n_L)(1-c)^2}{2}-\alpha F. \quad \text{(B.2.3)}$$

The optimal network configuration, $\boldsymbol{\delta}^{\mathbf{O}}$, is derived through the comparison of Eqs.

(B.2): namely,

Proposition 3

The optimal network configuration, $\boldsymbol{\delta}^{\mathbf{O}}$, *is characterized by:*

$$\boldsymbol{\delta}^{\mathbf{O}}=\begin{cases}(1,0,0) & \text{if } F>\bar{F}^O,\\ (1,1,0) & \text{if } \bar{F}^O\geq F\geq \tilde{F}^O,\\ (1,1,1) & \text{if } \tilde{F}^O>F,\end{cases} \quad (21)$$

where

$$\tilde{F}^O\equiv\frac{c(n_L+n_S)(2-l)\left[2-c(2+l)\right]}{2}, \quad (22.1)$$

$$\bar{F}^O\equiv\frac{(1+n_S)(1-c)^2}{2}+\frac{(n_L+n_S)(1-2c)^2}{2}. \quad (22.2)$$

Proof: The point-to-point is the optimal network configuration if:

$$SS^O(1,1,1)>SS^O(1,1,0)\Leftrightarrow\frac{c(n_L+n_S)(2-l)\left[2-c(2+l)\right]}{2}-F>0.$$

Solving this for F,

$$SS^O(1,1,1)>SS^O(1,1,0)\Leftrightarrow F<\tilde{F}^O\equiv\frac{c(n_L+n_S)(2-l)\left[2-c(2+l)\right]}{2}.$$

The hub-spoke network maximizes the social surplus if:

$$SS^{O}(1,1,0) > SS^{O}(1,0,0) \Leftrightarrow \frac{(1+n_S)(1-c)^2}{4} + \frac{(n_L+n_S)(1-2c)^2}{4} - F > 0.$$

Again, solving this for F,

$$SS^{O}(1,1,0) > SS^{O}(1,0,0) \Leftrightarrow F < \bar{F}^{O} \equiv \frac{(1+n_S)(1-c)^2}{2} + \frac{(n_L+n_S)(1-2c)^2}{2}.$$

Summarizing this, for $F < \tilde{F}^{O}$, the social surplus is maximized by forming the point-to-point; for $\tilde{F}^{O} \leq F \leq \bar{F}^{O}$, the hub-spoke is the optimal network; and for $\bar{F}^{O} < F$, serving to Routes LS is less efficient.

QED

Appendix C: Proofs of Propositions in Section 4

To derive the regulated network configuration, we compute the social surplus under the three alternative networks as follows:

$$SS(1,1,1)=\frac{(1+n_L)(1+m)(3+m)(1-c)^2}{2(2+m)^2}+\frac{3(1+n_S)(1-c)^2}{8}+\frac{3(n_L+n_S)(1-cl)^2}{8}-F\left[2+\alpha(1+m)\right], \tag{C.1.1}$$

$$SS(1,1,0)=\frac{(1+n_L)(1+m)(3+m)(1-c)^2}{2(2+m)^2}+\frac{3(1+n_S)(1-c)^2}{8}+\frac{3(n_L+n_S)(1-2c)^2}{8}-F\left[1+\alpha(1+m)\right], \tag{C.1.2}$$

$$\begin{aligned}SS(1,0,0)=&\frac{(1+n_L)\left[1+m-c\left(\gamma(1+3m)-2m\right)\right]^2}{2(2+m)^2}\\&+\frac{(1+n_L)\left[1-c\left(\gamma(1-2m)+2m\right)\right]\left[1-c\left(\gamma(1+m)-m\right)\right]}{(2+m)^2}\\&+\frac{m(1+n_L)\left[1-c\left(3m+2-\gamma(1+3m)\right)\right]\left[1-c(2\gamma-1)\right]}{(2+m)^2}-\alpha F(1+m).\end{aligned} \tag{C.1.3}$$

Comparing Eqs. (C.1), Proposition 5 derives the efficient network configuration, $\boldsymbol{\delta}^{\mathbf{R}}$:

Proposition 5

The regulated network configuration, $\boldsymbol{\delta}^{\mathbf{R}}$*, is characterized by:*

$$\boldsymbol{\delta}^{\mathbf{R}}=\begin{cases}(1,0,0) \text{ if } F>\bar{F}^R,\\(1,1,0) \text{ if } \bar{F}^R\geq F\geq\tilde{F}^R,\\(1,1,1) \text{ if } \tilde{F}^R>F,\end{cases} \tag{24}$$

where

$$\tilde{F}^R \equiv \frac{3c(n_L + n_S)(2-l)\left[2-c(2+l)\right]}{8}, \tag{25.1}$$

$$\bar{F}^R \equiv \frac{c(1+n_L)(\gamma-1)\left[3\left(2-c(1+\gamma)(1+2m^2)\right)+4m\left(1+c(\gamma-2)(1+2m^2)-m\right)\right]}{2(2+m)^2} + \frac{c^2m^2(1+n_L)(\gamma-1)^2}{2(2+m)^2} + \frac{3(1+n_S)(1-c)^2}{8} + \frac{3(n_L+n_S)(1-2c)^2}{8}.$$

(25.2)

Proof: From Eqs. (C.1), the government chooses the point-to-point if:

$$SS(1,1,1) > SS(1,1,0) \Leftrightarrow \frac{3c(n_L + n_S)(2-l)\left[2-c(2+l)\right]}{8} - F > 0.$$

Solving this for F, we have:

$$SS(1,1,1) > SS(1,1,0) \Leftrightarrow F < \tilde{F}^R \equiv \frac{3c(n_L + n_S)(2-l)\left[2-c(2+l)\right]}{8}.$$

Now, we compare the social surplus between the hub-spoke and the single route. According to the comparison, the hub-spoke is more efficient if:

$$\begin{aligned} &SS(1,1,0) > SS(1,0,0) \\ &\Leftrightarrow \frac{c(1+n_L)(\gamma-1)\left[3\left(2-c(1+\gamma)(1+2m^2)\right)+4m\left(1+c(\gamma-2)(1+2m^2)-m\right)\right]}{2(2+m)^2} \\ &\quad + \frac{c^2m^2(1+n_L)(\gamma-1)^2}{2(2+m)^2} + \frac{3(1+n_S)(1-c)^2}{8} + \frac{3(n_L+n_S)(1-2c)^2}{8} - F > 0. \end{aligned}$$

By solving this for F, we obtain the threshold at which the hub-spoke is as efficient as the single route:

$SS(1,1,0) > SS(1,0,0)$

$$\Leftrightarrow F < \bar{F}^R \equiv \frac{c(1+n_L)(\gamma-1)\left[3\left(2-c(1+\gamma)(1+2m^2)\right)+4m\left(1+c(\gamma-2)(1+2m^2)-m\right)\right]}{2(2+m)^2}$$

$$+\frac{c^2m^2(1+n_L)(\gamma-1)^2}{2(2+m)^2}+\frac{3(1+n_S)(1-c)^2}{8}+\frac{3(n_L+n_S)(1-2c)^2}{8}.$$

QED

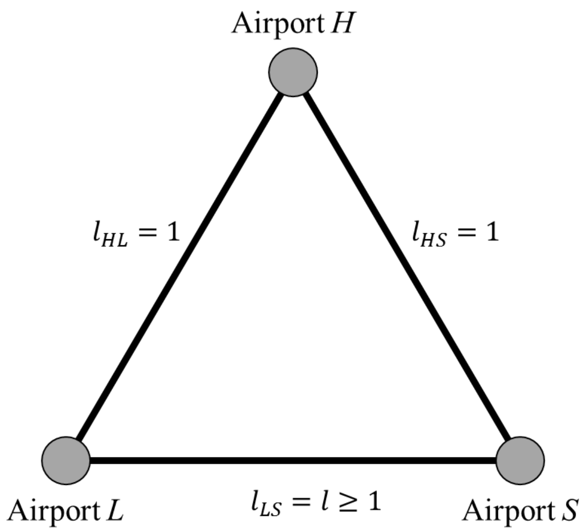


Figure 1: The Geography of the Economy

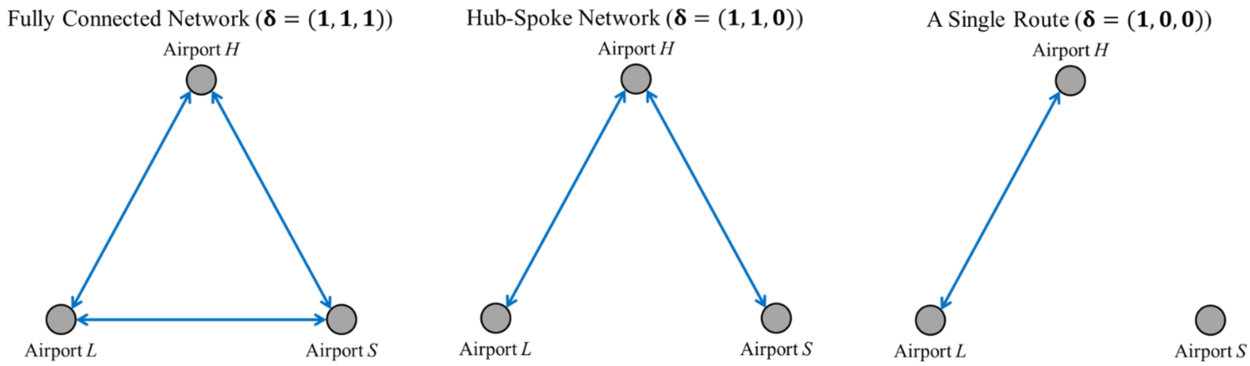
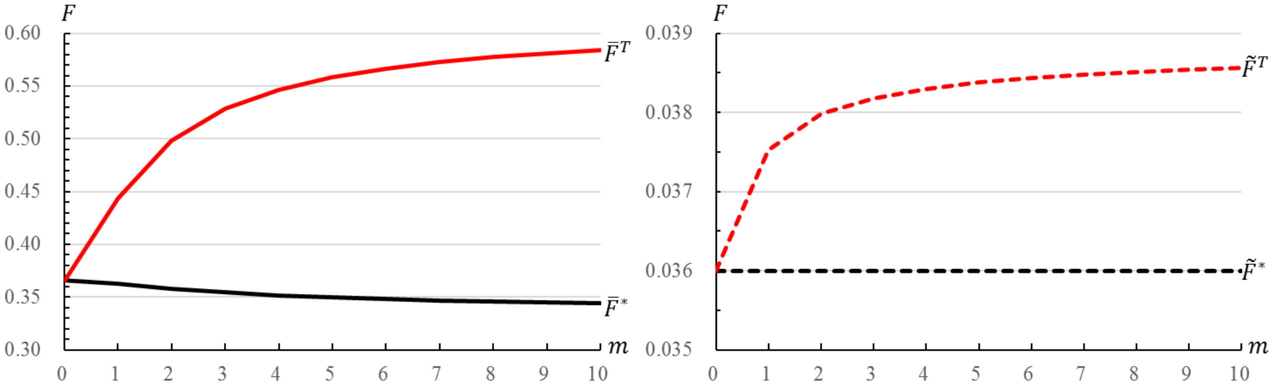


Figure 2: The Alternative Network Configurations

(1) The Effect of the Competition ($\gamma = 1.3$)



(2) The Effect of the Economies of Scope ($m = 1$)

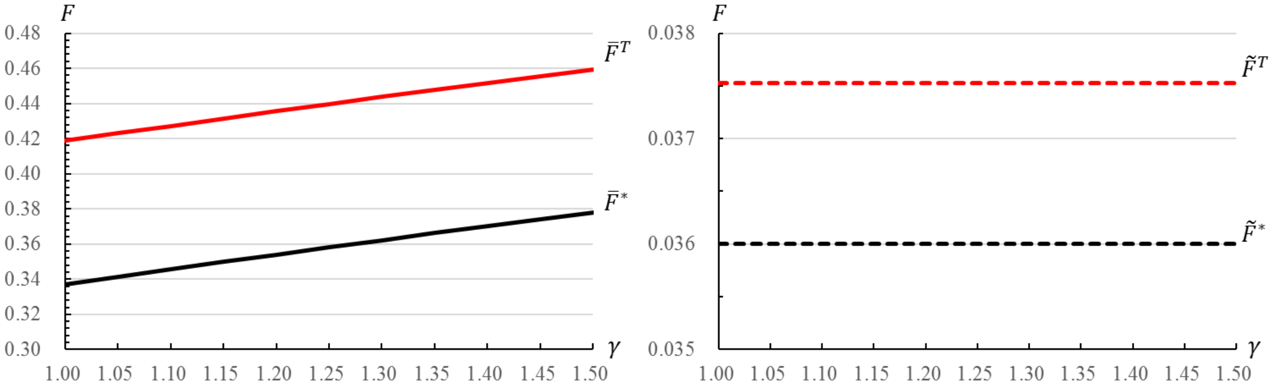


Figure 3: Thresholds of the Equilibrium under the Fee Scheme

($l = 1.2, c = 0.125, n_L = 0.8, n_S = 0.1$)

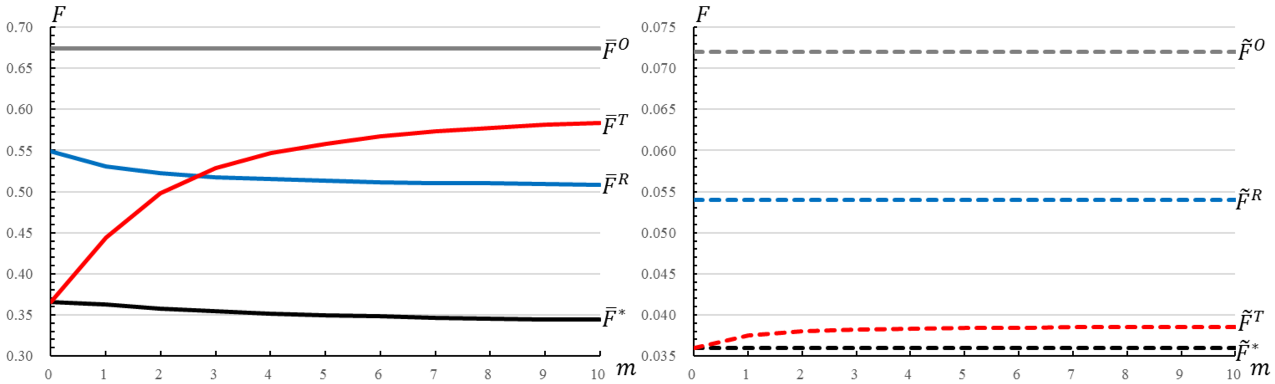
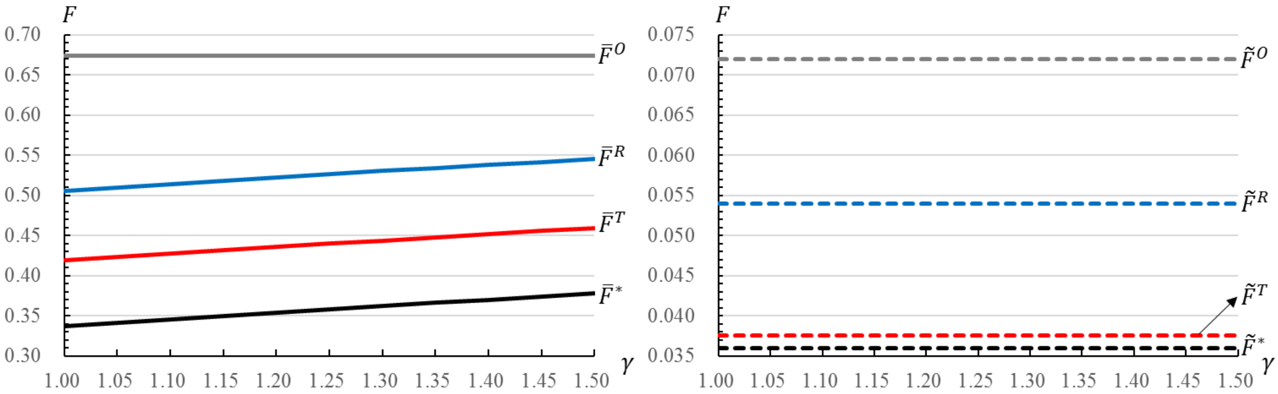


Figure 4: The Degree of the Competition and the Thresholds

($l = 1.2, c = 0.125, n_L = 0.8, n_S = 0.1, \gamma = 1.3$)

(1) The Less Competitive Case ($m = 1$)



(2) The More Competitive Case ($m = 4$)

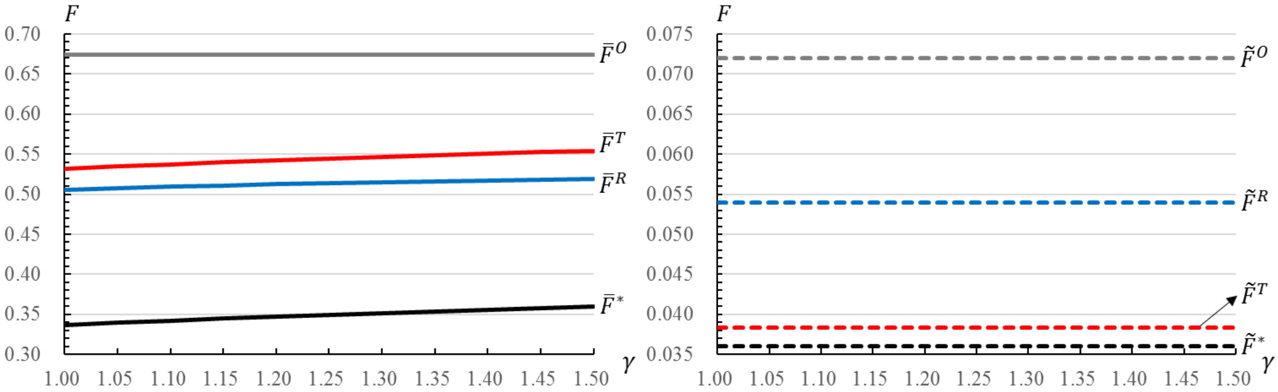


Figure 5: The Economies of Scope and the Thresholds

($l = 1.2, c = 0.125, n_L = 0.8, n_S = 0.1$)