E C O N O M I C S   B U L L E T I N

Alliances and entry in a simple airline network

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Abstract

This paper constructs an entry and code−sharing alliances game to demonstrate that the alliance between the incumbent carriers may play a significant role of entry deterrence in a given airline network. We show that incumbents can use the alliances as a credible threat to deter the entry of the potential entrants who have no significant cost advantage. This finding suggests that the role of the alliance in entry deterrence should be considered carefully when governments promote and maintain competition in the deregulated airline network markets.

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1. Introduction

Promoting and maintaining competition in deregulated airline markets is an essential concern in many regions. The post-deregulation U.S. aviation industry can be characterized as being highly oligopolistic (Shy 2001). Billette de Villemeur (2004) indicates that in spite of the deregulation of the "third package" that occurred in 1992, there is still a very low level of competition in present European aviation markets. The new entrants (Sky-mark Airlines and Air-Do) in Japan's deregulated airline markets are now suffering a deficit.

A stream of explanation for why the entry may be deterred or the new entrants may not survive has been offered by the previous literatures which focus on the adoption of the hub-spoke network. Oum et al. (1995) analyzes the effects of the strategic interaction between airlines on their network choice, and demonstrates that switching the network from a linear to a hub-spoke one will be useful in deterring entry. Hendricks et al. (1997) constructs an entry and exit game where the entrant enters into a spoke of the hub-spoke network operated by the incumbent, and shows that if the size of the network is large enough, a dominant strategy for the incumbent is not to exit from the spoke and the entrant is then forced to exit. Berechman et al. (1998) considers an entry game to show that changing the operating network from a fully connected network to a hub-spoke network can be used as a strategic device by the incumbent when it faces a threat of entry.

In contrast to these previous studies focusing on the network structure, the focus of this paper is on the dramatic growth of the code-sharing alliances[1]. In line with the fact that explosive numbers of code-sharing alliances have been concluded and some are even now being negotiated, a number of literatures have examined the economic effects of the code-sharing alliances. Among others, the theoretical analysis includes Park (1997), Brueckner (2001), and Lin (2004); empirical studies have been investigated by Youssef and Hansen (1994), Oum et al. (1996), Park and Zhang (1998), Brueckner and Whalen (2000), Park et al. (2001), and Park et al. (2003). However, according to my knowledge, there is little literature that argues the alliances issue based on the consideration of entry. In this paper, we try to construct an entry and alliances game to demonstrate that the alliance between the incumbent carriers may play a significant role of entry deterrence in a given airline network.

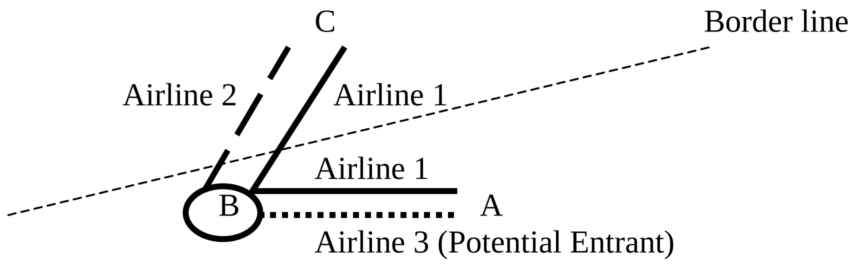
2. The Model

2.1. Airline network and entry alliance game

Let us consider a simple international hub-spoke network in which the issue of airline alliances and entry can be addressed. The network structure (depicted in Figure 1) in which the potential airline does not enter is similar to the hub-spoke network developed by Encaoua et al. (1996) and Lin (2004). There are three cities A, B and C, where cities A and B are located in the home country, and city C is located in a foreign country.

[1] A code-sharing alliance is a strategic cooperation between two airlines whereby each airline's designated code is shown on his partner's flights. The code-sharing flights are ticketed and provided as if they occurred on one partner airline. For details relative to code-sharing agreements, see Barron (1997).

Figure 1. A Simple International Hub-Spoke Network



Individuals living in each city wish to travel to other cities, thus there is round-trip demand between each city pair (AB, BC and AC). On the supply side, an incumbent carrier (Airline 1) uses city B as its hub to operate the hub-spoke network. Under bilateral agreements, another foreign carrier (Airline 2) provides international flights between city B and C as well. Because there is no direct flight between city A and C, travelers who want to travel from A to C or from C to A (say AC passengers) have to connect at the hub-city B. The AC passengers can travel either by on-line connecting flights (i.e., flying on Airline 1 only) or by interline connecting flights (i.e., changing airlines at the hub-city B). Since the possibility of interline services exists, Airline 1 competes with Airline 2 in the AC market for passengers to fly on its own BC flights. Thus there are three markets with different structure in the network before entry: direct domestic flight AB market (monopoly), direct international flight BC market (duopoly), and connecting flight AC market (partial duopoly).

Due to the deregulation in the domestic airline market, it is supposed that there exists a potential entrant (Airline 3) in the AB market. We consider an entry and alliances game with two-stages. In the first stage, the potential entrant (Airline 3) decides whether to enter the domestic AB market. In the second stage, the incumbent Airline 1 makes the decision of allying with Airline 2[2]. There are three possible cases to the game.

Case-NE: Airline 3 does not enter, Airline 1 operates the hub-spoke network and competes with Airline 2.

Case-E: Airline 3 enters on the domestic AB market, Airline 1 competes with Airline 2 and Airline 3 in each spoke.

Case-EA: Airline 1 allies with Airline 2 and competes with Airline 3.

Under the following assumptions, we will proceed to derive the outcomes for each case, respectively. And then use these outcomes to derive the sub-game perfect equilibrium.

2.2. **Basic assumptions**

Similar to the supposition that has been made in previous literature related to airline competition (e.g., Pels et al. 1997, Hendricks et al. 1997, and Lin 2004), the simple

[2] It is also possible to expect that Airline 1 could ally with Airline 2 before the entry of Airline 3. However, in our model the alliance before entry will lead to a monopoly in the whole network and this possibility may be eliminated by the regulation under the anticompetitive concern.

Bertrand-Nash competition without capacity constraint is supposed in our study. In a representative duopoly market, we either assume that the flights of both airlines are differentiated by the passengers due to the different departure times (see Encaoua et al. 1996), or assume that the passengers exhibit brand loyalty to a particular airline (see Brueckner and Whalen 2000). Following the specification in Brueckner and Whalen (2000), it is assumed that a given passenger will fly on Airline i if the fare satisfies $p^i < p^j + a$, where p^i represents the fare of Airline $i(i = 1,2, i \neq j)$, and a gives the passenger's monetary preference for Airline i. If a is uniformly distributed over the interval $[-\alpha/2, \alpha/2]$, the demand of Airline i (represented by x^i) can be generated and written as $x^i = 1/2 - (p^i - p^j)/\alpha$. Note, that one feature of this formulation is that the total demand of the market is always equal to one. Fare differences serve only to divide this fixed total demand between the two airlines. Another feature is a small value α (a tight distribution of passenger's preferences) makes the demand highly price sensitive. Without losing the generality of the analysis, let us assume that the reservation value of passengers on the monopoly market is large enough, and the demand of the monopoly market is always equal to one for convenience.

Following Hendricks et al. (1997), and Lin (2004), the costs of Airline $i(i = 1,2,3)$ to operate a direct flight are given by a marginal cost $c_i > 0$ and by a fixed cost $F_i > 0$. For simplification, it is supposed that the marginal cost of each airline is the same (i.e., $c_i \equiv c > 0$), and the costs associated with entry are ignored (see Oum et al. 1995, and Berechman et al. 1998).

3. Outcomes of three cases

3.1. Outcome of non-entry case (Case-NE)

In the network where Airline 3 does not enter, Airline 1 and Airline 2 compete not only in the BC market but also in the connecting AC market in which the possibility of interlining exists. Adopting the specification (sub-section 2.2) into the BC market, we have the demand functions as follows:

$$x_{BC}^1 = (1/2) - (1/\alpha)(p_{BC}^1 - p_{BC}^2) \tag{1}$$
$$x_{BC}^2 = (1/2) - (1/\alpha)(p_{BC}^2 - p_{BC}^1) \tag{2}$$

where x_{BC}^i and p_{BC}^i represent the demand and the fare of BC market for Airline $i(i = 1,2)$ respectively.

Similarly, the demand functions for AC market can be written as follows:

$$x_{AC}^{1+1} = (1/2) - (1/\alpha)p_{AC}^1 + (1/\alpha)(p_{AB}^1 + s_{BC}^2) \tag{3}$$
$$x_{AC}^{1+2} = (1/2) - (1/\alpha)(p_{AB}^1 + s_{BC}^2) + (1/\alpha)p_{AC}^1 \tag{4}$$

where x_{AC}^{1+1} and x_{AC}^{1+2} represents the demand of the passengers who travel by on-line connecting flights and by interline connecting flights, respectively. It should be noticed here, that we assume airlines adopt the discriminated fare strategy. Namely, Airline 1 sells the AB flight ticket for p^1_{AB}, the BC flight ticket for p^1_{BC}, and the connecting AC flight ticket for p^1_{AC}. To rule out the possibility that the connecting passengers choose to purchase two direct flight tickets instead of one connecting ticket, we impose the fare-arbitrage constraint $p^1_{AC} < p^1_{AB} + p^1_{BC}$ to Airline 1 (see Hendricks et al. 1997, Brucekner 2001, and Lin 2004). Further, since there is possibility of interlining, we assume Airline 2 sells interlining flight tickets. That is, Airline 2 sells the BC flight ticket to the BC passengers for p^2_{BC}, while to the interlining AC passengers for s^2_{BC}. To distinguish between BC and AC passengers, we impose the constraint $s^2_{BC} < p^2_{BC}$ to Airline 2 (see Hendricks et al. 1997) [3].

Given the demand functions for BC and AC markets (Eqs. (1)-(4)) and the cost structure of each airline, the profit-maximization problem of each airline could be formulated as follows:

$$\text{Airline 1: } \underset{p^1_{BC},\, p^1_{AC}}{Max}\ \pi_1 = (p^1_{AB} - c)\cdot(x^1_{AB} + x^{1+2}_{AC}) + (p^1_{BC} - c)\cdot x^1_{BC} + (p^1_{AC} - 2c)\cdot x^{1+1}_{AC} - 2F_1 \quad (5)$$

$$\text{Airline 2: } \underset{p^2_{BC},\, s^2_{BC}}{Max}\ \pi_2 = (p^2_{BC} - c)\cdot x^2_{BC} + (s^{1+2}_{BC} - c)\cdot x^{1+2}_{AC} - F_2 \quad (6)$$

In the monopoly AB market, it is assumed that Airline 1 charges monopoly fare p_M, which is supposed to be higher than the fare charged in the duopoly markets. Solving the above profit-maximization problem we obtain the Bertrand-Nash equilibrium listed in Table 1 (see Appendix A). In Table 1, the positive condition for the demand ($0 < x^{1+2,NE}_{AC} < 1$) is $p_m < (3/2)\alpha$. We impose this constraint for p_m to Airline 1, since under the bilateral agreements concerning international traffic rights, Airline 2 may claim that too high a monopoly fare would eliminate Airline 2 from AC market[4]. Note, the profit of Airline 3 in Case-NE is represented by $\pi_3^{NE} \equiv 0$.

3.2. Outcome of entry and non-alliance case (Case-E)

Entry of Airline 3 leads to a duopoly in the domestic AB market. Adopting the specification in sub-section 2.2, the demand function for AB market can be written as follows.

$$x^1_{AB} = (1/2) - (1/\alpha)(p^1_{AB} - p^3_{AB}) \quad (7)$$

$$x^3_{AB} = (1/2) - (1/\alpha)(p^3_{AB} - p^1_{AB}) \quad (8)$$

where x^i_{AB} and p^i_{AB} represent the demand and the fare of AB market for Airline

[3] The above two constraints are satisfied at the unconstrained solution to Airline 1's and Airline 2's optimization problems, so these constraints do not need to be imposed explicitly. This can be confirmed from Appendix A.

[4] A similar pricing constraint under which a hub-spoke network operator can not eliminate the spoke operator carrier from the connecting market has been made by Encaoua et al. (1996).

$i(i=1,3)$ respectively. The demand function for BC market remains the same as Eqs. (1)-(2). In the connecting AC market, it is assumed that passengers who prefer on-line connecting flights will fly on Airline 1, while passengers who prefer interline connecting flights will fly on Airline 2 and Airline 3. Under this assumption, the demand functions for AC market in this case can be written as follows:

$$x_{AC}^{1+1} = (1/2) - (1/\alpha)p_{AC}^{1} + (1/\alpha)(s_{AB}^{3} + s_{BC}^{2}) \tag{9}$$

$$x_{AC}^{3+2} = (1/2) - (1/\alpha)(s_{AB}^{3} + s_{BC}^{2}) + (1/\alpha)p_{AC}^{1} \tag{10}$$

where x_{AC}^{1+1} represents the demand of the passengers who travel by on-line connecting flights, x_{AC}^{3+2} represents the demand for the passengers who travel by interline connecting flights. s_{AB}^{3} represents the interline fare of Airline 3 charged on AC passengers. Now, the profit-maximization problem of each airline could be formulated by:

Airline 1: $$\underset{p_{AB}^{1},p_{BC}^{1},p_{AC}^{1}}{Max} \ \pi_1 = (p_{AB}^{1} - c)\cdot x_{AB}^{1} + (p_{BC}^{1} - c)\cdot x_{BC}^{1} + (p_{AC}^{1} - 2c)\cdot x_{AC}^{1+1} - 2F_1 \tag{11}$$

Airline 2: $$\underset{p_{BC}^{2},s_{BC}^{2}}{Max} \ \pi_2 = (p_{BC}^{2} - c)\cdot x_{BC}^{2} + (s_{BC}^{2} - c)\cdot x_{AC}^{3+2} - F_2 \tag{12}$$

Airline 3: $$\underset{p_{AB}^{3},s_{AB}^{3}}{Max} \ \pi_3 = (p_{AB}^{3} - c)\cdot x_{AB}^{3} + (s_{AB}^{3} - c)\cdot x_{AC}^{3+2} - F_3 \tag{13}$$

The Bertrand-Nash equilibrium can be derived by solving the profit-maximization problem of each airline (see Appendix A-Table 2).

3.3. Outcome of entry and alliance case (Case-EA)

In this case, Airline 1 and Airline 2 entered into a contract to operate code-share flights on the BC market[5]. Let us refer to the allied Airlines as “Airline 12” and assume that in Airline 12 a single decision-maker chooses the fares of their flights to maximize the joint profits. Furthermore, it is assumed that the alliance partners agree to equally share the profits from the BC market, and to share the profits from AC market with a share rate $\beta\,(0 < \beta < 1)$ due to the asymmetry. As well as the discriminated fare strategy assumption that has been made in the other cases, we assume that Airline 12 sells the AB flight ticket for p_{AB}^{1}, the BC flight ticket for p_{BC}^{12}, and the connecting AC flight ticket for p_{AC}^{12}. While Airline 3 sells the AB flight ticket for p_{AB}^{3} to AB passengers, and for s_{AB}^{3} to AC passengers.

In this case, the demand function for AB market remains the same as Eqs. (7)-(8). BC market becomes a monopoly. The demand functions for AC market now can be written as follows:

[5] This type of alliance (parallel alliance) has been argued by Park (1997), and Brueckner (2001).

$$x_{AC}^{1+12} = (1/2) - (1/\alpha)p_{AC}^{12} + (1/\alpha)(s_{AB}^{3} + p_{BC}^{12}) \tag{14}$$
$$x_{AC}^{3+12} = (1/2) - (1/\alpha)(s_{AB}^{3} + p_{BC}^{12}) + (1/\alpha)p_{AC}^{12} \tag{15}$$

where x_{AC}^{1+12} represents the demand of the passengers who travel by on-line connecting flights (i.e., flying on the allied Airline 12 only), x_{AC}^{3+12} represents the demand for the passengers who travel by interline connecting flights (i.e., flying on Airline 3 and Airline 12).

The profit-maximization problems of Airline 12 and Airline 3 are formulated as follows:

Airline 12: $\underset{p_{AC}^{12},\, p_{AB}^{1}}{Max}\ \Pi_{1+2}$

$$= (p_{BC}^{12} - c)\cdot(x_{BC}^{12} + x_{AC}^{3+12}) + (p_{AC}^{12} - 2c)\cdot x_{AC}^{1+1} + (p_{AB}^{1} - c)\cdot x_{AB}^{1} - 2F_1 - F_2 \tag{16}$$

Airline 3: $\underset{p_{AB}^{3},\, s_{AB}^{3}}{Max}\ \pi_3 = (p_{AB}^{3} - c)\cdot x_{AB}^{3} + (s_{AB}^{3} - c)\cdot x_{AC}^{3+12} - F_3$ (17)

Similarly, the Bertrand-Nash equilibrium can be derived, and the equilibrium values are listed in Table 3 (see Appendix A).

4. Comparison of the outcomes

According to Table 2 and 3, we give the following lemmas to show the effects on the fares, demands and airlines' profits resulting from the alliance.

Lemma 1. In the airline network where Airline 3 entered, and Airline 1 allied with Airline 2:

(a) the fare of the international BC market rises from the duopoly fare to the monopoly fare.

(b) in the connecting AC market, both the fare of the on-line connecting flights and interline connecting flights rises. Corresponding to these fare changes, the demand of on-line connecting flights increases, while the demand of interline connecting flights decreases.

(c) the joint profits of the allied airlines increase (compared to the sum of the profits of these two airlines obtained in the pre-alliance equilibrium). While, the profits of Airline 3 decrease.

Proof. See Appendix B.

Intuitively, the fare changes in the AC market can be explained based on the strategically substitutive and complementary relationship between Airline 12 and Airline 3[6]. Airline 12 can raise the fare of BC flight p_{BC}^{12} and the fare of the on-line connecting flights p_{AC}^{12} under the alliance. For Airline 3, the best response to Airline

[6] For the definition of strategic substitutes and complements, Bulow et al. (1985) is useful.

12's fare-raising of p_{BC}^{12} is to lower the interline fare s_{AB}^{3} due to the strategically substitutive relationship, while the best response to Airline 12's fare-raising of p_{AC}^{12} is to raise the interline fare s_{AB}^{3} due to the strategically complementary relationship with Airline 12. Airline 3's interline fare s_{AB}^{3} falls since the pressure of fare-lowering is stronger than the fare-raising. The total fare of interline connecting flights ($s_{AB}^{3} + p_{BC}^{12}$) rises too, since the raising of p_{BC}^{12} is larger than the lowering of s_{AB}^{3}. The demand for on-line connecting flights increases while the demand for interline connecting flights decreases, since the fare-raising of the on-line connecting flights is smaller than the total fare-raising of the interline connecting flights. Thus fare and demand changes like in lemma 1 emerge, and the corresponding profit changes can be obtained.

Further, according to Table 2 and 3 we have the following lemma to give a range of β (the share rate of profits from AC market between the allied airlines) in which the profits of each alliance partner increase, which means both airlines have the incentive to ally with each other.

Lemma 2. There exists a range of β *in which* $\pi_1^{EA}(\beta) \geq \pi_1^{E}$ *and* $\pi_2^{EA}(\beta) \geq \pi_2^{E}$.

Proof. See Appendix B.

From lemma 1 and 2, we have the following two propositions to show the sub-game perfect equilibrium to the entry and alliance game.

Proposition 1. Given a sufficiently small fixed cost of the entrant (Airline 3) such that $\pi_3^{NE}(\equiv 0) < \pi_3^{EA} < \pi_3^{E}$, *the unique sub-game perfect equilibrium consists of Airline 3 entering and Airline 1 allying with Airline 2.*

Proposition 2. Give a sufficiently large fixed cost of the entrant (Airline 3) such that, $\pi_3^{EA} < \pi_3^{NE}(\equiv 0) < \pi_3^{E}$, *the unique sub-game perfect equilibrium consists of Airline 1 allying with Airline 2, and Airline 3 not entering.*

Proposition 1 and Proposition 2 describe that given a fixed cost, the entrant may obtain positive profits by entering into the domestic market in the first stage. However the positive profits may reduce to a negative value, due to the alliances between the incumbent airlines in the second stage. In other words, the incumbents can use the alliances as a credible threat to deter the entry of the potential entrants who have no significant cost advantage.

5. Concluding Remarks

The main result of our study that the alliances can be used as a credible commitment for entry deterrence has strong ties to the original insight of Dixit (1980) on the role of capital investment, as well as to the finding of Oum et al. (1995) and Hendricks et al. (1997) on the role of the hub-spoke network. The result of the present paper implies that the role of the alliance on the entry deterrence should be considered carefully when governments promote and maintain competition in the deregulated airline network markets.

Appendix A. Outcomes for three cases (Table 1-3)

Table 1. The Bertrand-Nash equilibrium with non-entry

	AB market	BC market	AC market
Fares	$p_{AB}^{1,NE} \equiv p_M$	$p_{BC}^{1,NE} = p_{BC}^{2,NE} = (1/2)\alpha + c$	$p_{AC}^{1,NE} = (1/2)\alpha + (5/3)c + (1/3)p_M$ $s_{BC}^{2,NE} = (1/2)\alpha + (4/3)c - (1/3)p_M$
Demands	$x_{AB}^{1,NE} = 1$	$x_{BC}^{1,NE} = x_{BC}^{2,NE} = 1/2$	$x_{AC}^{1+1,NE} = (1/2) + (1/3\alpha)p_m$ $x_{AC}^{1+2,NE} = (1/2) - (1/3\alpha)p_m$ where $(p_M - c) \equiv p_m$
Profits	$\pi_1^{NE} = (1/2)\alpha + (11/6)p_m - (2/9\alpha)p_m^2 - 2F_1$, $\pi_2^{NE} = (1/2)\alpha - (1/3)p_m + (1/9\alpha)p_m^2 - F_2$,		

Table 2. The Bertrand-Nash equilibrium with entry

	AB market	BC market	AC market
Fares	$p_{AB}^{1,E} = p_{AB}^{3,E} = (1/2)\alpha + c$	$p_{BC}^{1,E} = p_{BC}^{2,E} = (1/2)\alpha + c$	$p_{AC}^{1,E} = (5/8)\alpha + 2c$ $s_{AB}^{3,E} = s_{BC}^{2,E} = (3/8)\alpha + c$
Demands	$x_{AB}^{1,E} = x_{AB}^{3,E} = 1/2$	$x_{BC}^{1,E} = x_{BC}^{2,E} = (1/2)$	$x_{AC}^{1+1,E} = 5/8$ $x_{AC}^{3+2,E} = 3/8$
Profits	$\pi_1^E = (57/64)\alpha - 2F_1$, $\pi_2^E = (25/64)\alpha - F_2$, $\pi_3^E = (25/64)\alpha - F_3$		

Table 3. The Bertrand-Nash equilibrium with entry and alliance

	AB market	BC market	AC market
Fares	$p_{AB}^{1,EA} = p_{AB}^{3,EA} = (1/2)\alpha + c$	$p_{BC}^{12,EA} \equiv p_M$	$p_{AC}^{12,EA} = (1/2)\alpha + (5/3)c + (1/3)p_M$ $s_{AB}^{3,EA} = (1/2)\alpha + (4/3)c - (1/3)p_M$
Demands	$x_{AB}^{1,EA} = x_{AB}^{3,EA} = 1/2$	$x_{BC}^{12,EA} = 1$	$x_{AC}^{1+12,EA} = (1/2) + (1/3\alpha)p_m$ $x_{AC}^{3+12,EA} = (1/2) - (1/3\alpha)p_m$
Profits	Joint-profits $\Pi_{1+2}^{EA} = (1/2)\alpha + (11/6)p_m - (2/9\alpha)p_m^2 - 2F_1 - F_2$, $\pi_1^{EA}(\beta) = (1/4)\alpha + (1/2)p_m + \beta\left[(5/6)p_m + (1/4)\alpha - (2/9\alpha)p_m^2\right] - 2F_1$ $\pi_2^{EA}(\beta) = (1/2)p_m + (1-\beta)\left[(5/6)p_m + (1/4)\alpha - (2/9\alpha)p_m^2\right] - F_2$ $\pi_3^{EA} = (1/2)\alpha - (1/3)p_m + (1/9\alpha)p_m^2 - F_3$		

Appendix B.

Proof for Lemma 1:
According to Table 2 and 3, it can be easily shown that the condition for the changes of fares and demands like in lemma 1-b is $p_m > (3/8)\alpha$. Given the assumption that the monopoly fare is higher than the duopoly fare (i.e., $p_m > (1/2)\alpha$), these changes hold.

Again, according to Table 2 and 3 we have

$$\Pi_{1+2}^{EA} - (\pi_1^E + \pi_2^E) = -(1/576\alpha)[(450\alpha - 64p_m)(\alpha - 2p_m) - 92\alpha \cdot p_m] \qquad (A.1)$$

$$\pi_3^{EA} - \pi_3^E = (1/576\alpha)(21\alpha - 8p_m)(3\alpha - 8p_m) \qquad (A.2)$$

Recall the positive condition for the demands ($p_m < (3/2)\alpha$). It can be shown that Eq. (A.1) is positive and Eq. (A.2) is negative for any $(1/2)\alpha < p_m < (3/2)\alpha$. QED.

Proof for lemma 2:
According to Table 2 and 3, it can be shown that the condition for $\pi_1^{EA}(\beta) \geq \pi_1^E$ is $\beta \geq \beta_S \equiv [(41/64)\alpha - (1/2)p_m]/[(1/4)\alpha + (5/6)p_m - (2/9\alpha)p_m^2]$, and the condition for $\pi_2^{EA}(\beta) \geq \pi_2^E$ is $\beta \leq \beta_L \equiv [-(9/64)\alpha + (4/3)p_m - (2/9\alpha)p_m^2]/[(1/4)\alpha + (5/6)p_m - (2/9\alpha)p_m^2]$. Here, we have a range of β where ($\beta_S \leq \beta \leq \beta_L$) for any $(1/2)\alpha < p_m < (3/2)\alpha$. QED.

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