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Join Logistics Sharing Alliance or Not? Incentive Analysis of Competing E-commerce Firms with Promised-Delivery-Time

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Abstract

E-commerce firms such as JD.com have launched logistics sharing alliance (LSA) by providing logistics services to the society. However, should their rivals having logistics service disadvantages join the LSA? In this paper, we formulate competing e-commerce firms' incentives regarding logistics cooperation via LSA. Firm A (she) offers LSA. Firm B (he) may guarantee customers a promised delivery time (PDT), although he has logistics services disadvantages. Without PDT, we find that firm B's profit performance joining LSA will be hurt when the market competition intensity degree is either high or low. We characterize firm B's total sales and the allocation ratio because of firm A's logistics sharing to explain this interesting finding. In contrast, when firm B has PDT guarantee, we find that he will join LSA when the PDT cost is high and the competition intensity degree is low. That is, PDT increases firm B's incentives to join LSA when he faces mild competition from firm A.

Keywords: *Logistics sharing; Co-opetition; Promised delivery time; E-commerce.*

1 Introduction

Nowadays, when customers purchase from e-commerce firms, they actually pay for "product +logistics". Many customers, especially those office ladies and salaried men, sometimes even buy more expensive products from JD.com than the other firms just because JD.com offers high quality logistics services. It is reported that JD promises fast logistics by offering "211 Delivery Commitment" in 23 cities[1], which means (1) if customers order before 11:00 am, the products would be delivered in the same day. (2) if customers order before 11:00 pm, the products would be delivered before 3:00 pm in the next day. In six core cities of JD's logistics service network, the products can reach customers within three hours. Till now, JD has achieved a rate of over 90% of orders delivered the same or the next day that no other e-commerce firms can match.

Undoubtedly, JD has realized that its fast logistics has become its core competitiveness which might help JD generate additional profits besides attracting customers to purchase goods. In practice, JD launched logistics sharing alliance (LSA) in November 2016 where all the e-commerce firms including JD's competitors, are allowed to utilize JD's automated smart fulfillment centers, advanced delivery information systems, large scale logistics service network etc., to satisfy customers' high logistics service requirements[2]. Then the rivals may become JD's logistics service customers, which helps JD generate logistics profits and improve the social logistics service levels.

Regarding the competing e-commerce firms, JD's LSA seems beneficial because of the high customer satisfaction about logistics services. However, sharing logistics with JD can be a double-edged sword: The competing e-commerce firms' logistics costs are controlled by JD, which provides JD the flexibility to balance the gains from vertical competition (via logistics service fee) and horizontal competition (via product selling). This helps JD gain advantages when she makes strategic decisions about logistics service fee, retail price, demand size etc., especially when the competing e-commerce firms are also customers of "JingDong Logistics".

Being aware of the foregoing reasons, whether the competing e-commerce firms join JD's

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[1] https://heyjunbro.files.wordpress.com/2015/09/eca491eab5adec9db8ed84b0eb84b7_ed8bb0ec9794eca990eb8f99-jdeb8bb7ecbbb4-ecb49deab090-jaff-tian-director-of-business-development-jd-com.pdf

[2] https://techcrunch.com/2017/04/25/jd-com-creates-new-unit-for-its-logistics-services/

LSA becomes a strategic decision. Some firms choose to build their own logistics service networks, although that incurs overlapping investment, and their logistics services are not competitive compared to JD's. Some other firms choose to join JD's LSA, so as to focus on product competition rather than logistics service competition. One typical example is Tootoo, a start up e-commerce firm providing organic, natural and high-quality food for customers[3]. In the early stage, Tootoo tried to build his own logistics service network. However, in the recent years, more and more e-commerce firms have promised delivery time (PDT) to customers (e.g., same day delivery; next day delivery). Tootoo's products have to be fresh, so PDT competition significantly influences his profit and service performances. His own logistics service disadvantages are further strengthened because of the arising PDT competition in the fresh food industry. Consequently, Tootoo gave up his own logistics network and joined JD's LSA, which helped Tootoo realize the same day delivery, although JD had fresh food business and competed with Tootoo. We note that, third-party logistics firms such as SF Express can also provide efficient delivery. However, using e-commerce firms' LSA results in a co-opetitive supply chain structure, which strategically changes the decisions of Tootoo and JD. For Tootoo, if he chooses third-party logistics firms, his cost is increased, the logistics service level is improved, but the equilibriums are qualitatively similar to that when he uses his own logistics service network. Being aware of this, we focus on the interesting co-opetitive structure when Tootoo uses JD's LSA.

Therefore, our research questions are: (1) What are new in the decisions of logistics sharing alliance, regarding its benefits (e.g., reduced cost, shortened PDT) and strategic disadvantages for the competing partners (e.g., JD and Tootoo)? (2) How about the incentives of Tootoo and JD to cooperate with each other under LSA? (3) Considering PDT competition, will we obtain new findings?

We build stylized models comprising an e-commerce firm (firm A, she) offering LSA and a competing e-commerce firm (firm B, he) having logistics disadvantages. Firm A and B sell substitutable products so they are downstream competitors. We consider three scenarios (1) Scenario N: Firm B uses his own logistics although having disadvantage. (2) Scenario S: Firm B uses firm A's sharing logistics. (3) Scenario N': Firm B has to guarantee a PDT because of

[3] http://www.tootoo.cn/ (in Chinese)

time-sensitive customers, but still uses his own logistics. Firm A and B are hence involved in a two-dimensional competition including PDT and demand/output competitions. If firm B uses his own logistics, he has service disadvantage over firm A, but is not influenced by firm A's logistics pricing decisions. If firm B joins firm A's logistics sharing alliance, then they are involved in a co-opetitive supply chain where their logistics service levels are identical. Firm B has to pay for firm A's high-quality logistics services. If firm B guarantees a PDT, then he incurs a PDT cost for late delivery. His logistics disadvantage hence becomes a decision variable, which results in new results compared to Scenario N and S where the logistics disadvantage is exogenously given.

Our findings are summarized as follows. First, we characterize the equilibrium outcomes including the quantities, the logistics service fee (in Scenario S) and the profits of firm A and firm B in three scenarios. We find firm B's profit is hurt in LSA when the product competition intensity degree is either high or low. The reasons are as follows. Given a low competition intensity degree, firm B faces mild competition, and his market share and total sales are large. Being aware of this, firm A tends to charge a high unit logistics service fee, which also increases the double marginalization effect. That is, although firm B has a relatively high profit, this is snatched by firm A through a high logistics service fee. Firm A's pricing power holds the key. In contrast, given a high competition intensity degree, firm B's market share is hurt and firm B's logistics cost is high because firm A has to reduce the downstream competitiveness of firm B by charging a high logistics service fee. These forces significantly lower firm B's incentives to join firm A's LSA.

Second, we consider the situation that firm B guarantees a PDT to customers. We compare the results with and without PDT and find that firm B has incentives to join firm A's LSA when the market competition is mild and the PDT cost is high. That's because the introduction of PDT would restrict firm B's demand size because of the PDT workload cost. This restriction is significant when the competition intensity degree is low.

Our contributions are as follows. First, we characterize the incentive alignment opportunities of competing e-commerce firms under newly-launched LSA. This differs our work from those on co-opetitive supply chain by formulating "product + logistics service" competition and cooperation, which changes the profit allocation rules in an e-commerce system. Second, we consider PDT's impact and find that, small e-commerce firms such as Tootoo with PDT competition are suggested to join JD's LSA when the market competition is mild and the PDT cost is high. The introduction of PDT improves the logistics service level, but constrains the sales volume. Therefore, small e-commerce firms are suggested to be serious about the tradeoffs among logistics service quality, sales volume and two-dimensional competition with large e-commerce firms such as JD.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 describes the model setting. In section 4, we analyze firm B's incentives to join firm A's LSA without PDT. Section 5 discusses firm B's PDT guarantee, firm B's logistics service cost and considers a revenue-sharing contract between two firms. Section 6 concludes this paper.

2 Literature Review

Our work is related to the studies about service outsourcing and sharing logistics. Allon and Federgruen (2006) analytically characterize competing retailers' benefits and losses under price and time competition if they outsource their service to a common service provider. Santibanez Gonzalez et al. (2016) develop an analytical model to help the logistics service providers evaluate options and make decisions, using a variational inequality approach. Zhao et al. (2016) investigate the influences of advertising on a start-up service provider by repeat purchase mechanism. Shen et al. (2017) study how the online retail service provider's service level is determined by a luxury fashion supply chain's demand changes and social influences. Liu et al. (2017) use a multi-objective programming model to minimize the total cost of a logistics service supply chain. They consider the impact of customer request's time window. Liu et al. (2018) further study how a logistics service integrator allocates the logistics service order to two competing logistics service providers with fairness concerns. Different from the above studies, our work considers the logistics service outsourcing/sharing in a co-opetitive supply chain, where the LSA provider also competes with the LSA user in the product selling business. We note that, the aforementioned works are all based on optimization models, whereas we focus on the incentive alignment issues between two competitors regarding LSA offering and adopting.

Our work also follows the studies about alliance joining. Büyüközkan et al. (2008) study how companies choose their logistics alliance partners using a fuzzy logic approach. Garg (2016) develops an analytic hierarchy process model to select strategic alliance partner in the airline industry. Hsu et al. (2017) investigate two competing buyers' incentives to join a leader-based procurement alliance when the buyers have different bargaining powers over the supplier. Wang et al (2017) characterize two competing reginal logistics service providers' incentives to form an alliance facing a powerful mainline logistics service provider, when either the reginal or the mainline logistics service provider can canvass for cargos. Different from the above studies, our work presents a model where the LSA provider's incentives and the LSA user's incentives are both studied. We characterize their incentive conflicts and alignment opportunities in a "product + logistics" system.

Our work is related to the studies on channel co-opetition. Chiang et al. (2003) find the development of an e-commerce channel might benefit both the manufacturer and the retailer, although competition with the existing retail channel arises. Tsay et al. (2004) suggest that channel conflict caused by a manufacturer's direct sale is not always detrimental to the reseller. Both the manufacturer and the reseller can benefit from that if the manufacturer sets an appropriate price. Arya et al. (2007) find supplier encroachment will lead to a lower wholesale price, mitigate double marginalization problems, and promote supply chain efficiency. Li et al. (2010) study the impact of supplier competition and supply disruption in a dual channel system. They also study the resulted supply chain cooperation opportunities. Wang et al. (2013) and Niu et al. (2015) study the contract manufacturer's ordering and pricing sequences when its self-branded product competes with the original equipment manufacturer (OEM)'s. The key difference between our research and these studies is that we study a two-dimensional competition consisting demand and PDT competitions. The supply chain parties' decisions especially their cooperation incentives via logistics sharing alliance will be significantly influenced.

Finally, our work is related to the literature on multi-dimensional competition consisting PDT. So (2000) considers a model in which demand is sensitive to both price and delivery time guarantees. He finds firms compete less on price, and the equilibrium prices become higher when demands are more sensitive to time. Boyaci and Ray (2003) consider price and time sensitive demand to study the impact of capacity constraint on firms' decisions of price and time. Liu et al. (2007) study a decentralized supply chain where demand is lead-time-sensitive. They find the profit loss because of channel decentralization might be reduced. Hua et al (2010) investigate how the delivery lead time and customer acceptance of a direct channel influence pricing decisions in a centralized and a decentralized dual-channel supply chain, respectively. Wu et al. (2012) investigate a newsvendor problem with endogenous quoted lead-time. They provide a method to determine the unique optimal selling price, lead-time and order quantity. Wang et al. (2017) study mainline carriers' upstream entry decisions when the regional carries are engaged in a joint demand and PDT competition. Difference from the studies above, we consider e-commerce firms' incentives to join a logistics sharing alliance or not. If yes, there is a co-opetitive supply chain that is not studied by the foregoing works. If no, there is an asymmetric two-dimensional competition because one firm has logistics disadvantage, which is not studied by the foregoing works, either.

3 Model

We use an analytical game theorical model which is developed according to a representative customer's utility. Following Singh and Vives (1984), the customers' utility function can be formulated to be quadratic and strictly concave,

$$U(q_{\mathrm{A}}, q_{\mathrm{B}}) = a_{\mathrm{A}} q_{\mathrm{A}} + a_{\mathrm{B}} q_{\mathrm{B}} - (b_{\mathrm{A}} q_{\mathrm{A}}^2 + 2\gamma q_{\mathrm{A}} q_{\mathrm{B}} + b_{\mathrm{B}} q_{\mathrm{B}}^2)/2,$$

where q_i is the amount of product $i, a_i, b_i > 0,\ b_{\mathrm{A}} b_{\mathrm{B}} - \gamma^2 > 0$ and $a_i b_j - a_j \gamma > 0$ for $i \neq j,\ i = \mathrm{A}, \mathrm{B}$. The first order conditions for maximizing $U(q_{\mathrm{A}}, q_{\mathrm{B}}) - p_{\mathrm{A}} q_{\mathrm{A}} - p_{\mathrm{B}} q_{\mathrm{B}}$ lead to a linear demand structure, where p_i is the price of products *i*. Inverse demand functions are as follows, $p_{\mathrm{A}} = a_{\mathrm{A}} - b_{\mathrm{A}} q_{\mathrm{A}} - \gamma q_{\mathrm{B}}$ and $p_{\mathrm{B}} = a_{\mathrm{B}} - \gamma q_{\mathrm{A}} - b_{\mathrm{B}} q_{\mathrm{B}}$. Following literature such as Tsay and Agrawal (2000), Wang et al. (2017) and Chen and Wu (2018), we have $a_{\mathrm{A}} = a_{\mathrm{B}} = a,\ \gamma = \mathrm{b}$ and $b_{\mathrm{A}} = b_{\mathrm{B}} = 1$. Hence, the inverse demand function is: $p_i = a - b q_i - q_j$, where $i \neq j,\ i = \mathrm{A}, \mathrm{B}$.

We consider two scenarios defined as follows:

(1) Scenario N, two firms use their own logistics services. We assume the customers are sensitive to the delivery time. Based on previous literature (Tsay and Agrawal 2000, Boyaci and Ray 2003, Wang et al. 2017 and Wu and Chen 2018), the inverse demand functions of two firms and their profits are, respectively

$$p_A = a - q_A - b q_B - l_A + d\, l_B$$

$$p_B = a - q_B - bq_A - l_B + d\, l_A$$

$$\pi_A = p_A q_A$$

$$\pi_B = p_B q_B$$

where $b \in (0,1)$ measures the product competition intensity degree of two firms. If $b = 0$, the two firms' products are independent; if $b = 1$, their products are perfectly substituted. l_i is exogenously given and measures the delivery time of firm i. d represents the degree of PDT sustainability. Because firm B's logistics service is inferior to firm A's, which is reflected by firm B's longer delivery time. Without loss of generality, we assume $l = l_B - l_A$, $l_A = 0$ and $d = 1$. Therefore, the inversed demand function is simplified as

$$p_A = a - q_A - bq_B$$

$$p_B = a - l - q_B - bq_A$$

l measures the disadvantage of firm B's delivery time compared to firm A. In the extension, we make l as a decision variable by allowing firm B to determine his PDT.

(2) Scenario S, in which firm B uses firm A's sharing logistics and his disadvantage in delivery time is eliminated. However, firm B has to pay a logistics service fee per unit delivery. The inverse demand functions and profit functions are, respectively

$$p_A = a - q_A - bq_B$$

$$p_B = a - q_B - bq_A$$

$$\pi_A = p_A q_A + \mathrm{w} \mathrm{q}_B$$

$$\pi_B = (p_B - w)q_B$$

The notations are summarized in Table 1.

Table 1. Summary of notations

Notation	Description
a	The market potential
A	Firm A
B	Firm B
l	The delivery time disadvantage of firm B
b	The competition intensity degree of two firms' products
w	The unit logistics service fee charged by firm A

c^T	The delay cost per unit delivery per unit time of firm B
c^L	The marginal PDT cost
q_i	The quantity of firm i ($i \in \{A, B\}$)
p_i	The price of firm i's products ($i \in \{A, B\}$)
π_i	The profit of firm i ($i \in \{A, B\}$)

We assume $l \in \left(0, \frac{a}{2}\right)$ to ensure all variables to be positive. The event sequences are illustrated by Figure 1:

(1) Firm B chooses to join firm A's LSA or not.

(2) If firm B joins the LSA, firm A decides the logistics services fee. Then the two firms decide their quantities simultaneously. If firm B uses his own logistics, firm A and firm B decide their quantities simultaneously.

Therefore, for Tootoo, if he chooses to use his own logistics service, he would not be influenced by JD's logistics service fee decisions, but has a disadvantage of logistics service over JD. If Tootoo gives up his own logistics service and joins JD's LSA, there would arise a co-opetitive supply chain structure where JD and Tootoo are cooperators in logistics service but they are competitors in downstream product selling. For Tootoo, although his logistics service is improved, he should pay a logistics service fee to JD. Then we use our analytical model to illustrate Tootoo's incentives of joining JD's LSA. The details are in section 4.

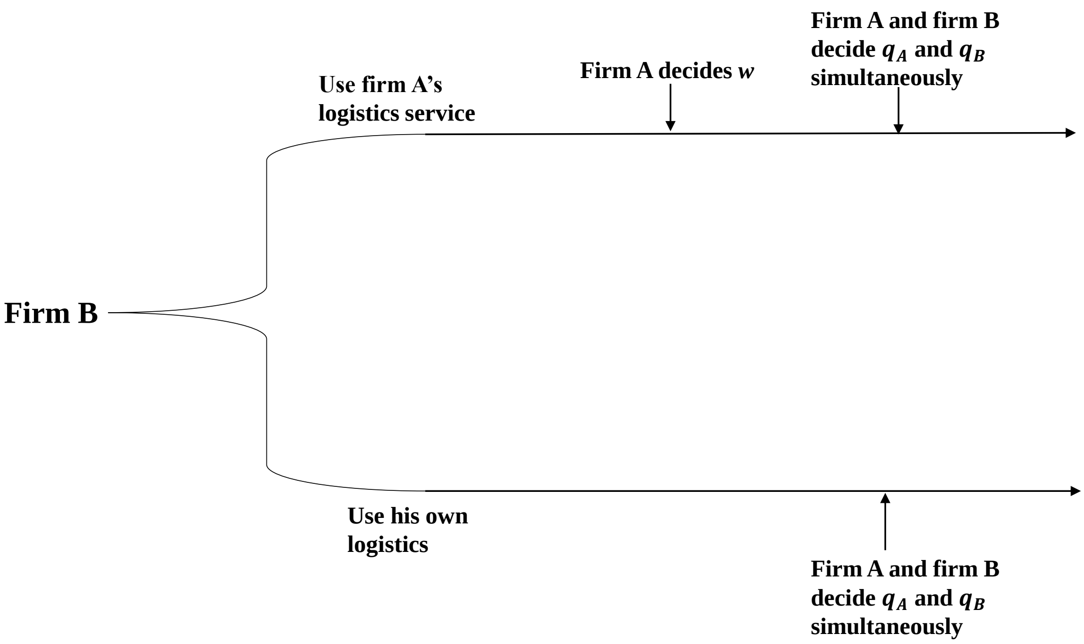

Figure 1. The event sequences

4 Analysis

For the rest of our paper, we incorporate superscripts on the optimums: N and S denote Scenario N and Scenario S, respectively. For example, q_A^N means firm A's optimal quantity in Scenario N. We use backward induction to solve the problem. And we have the equilibrium outcomes in Scenario N and Scenario S:

Lemma 1 *The equilibrium outcomes in Scenario N are*

$$q_A^N = \frac{a(2-b)+bl}{4-b^2},\ q_B^N = \frac{a(2-b)-2l}{4-b^2},\ \pi_A^N = \frac{[a(2-b)+bl]^2}{(4-b^2)^2},\ \pi_B^N = \frac{[a(2-b)-2l]^2}{(4-b^2)^2}.$$

Lemma 2 *The equilibrium outcomes in Scenario S are*

$$w^S = \frac{a(2-b)(4+2b-b^2)}{16-6b^2},\ q_A^S = \frac{a(2-b)(4+b)}{16-6b^2},\ q_B^S = \frac{2a(1-b)}{8-3b^2},\ \pi_A^S = \frac{a^2(6-b)(2-b)}{4(8-3b^2)},\ \pi_B^S = \frac{4a^2(1-b)^2}{(8-3b^2)^2}.$$

Then we compare two firms' preferences in the Scenario N and S to figure out under what conditions firm A and firm B would reach an agreement on joining LSA. We find in Scenario S the logistics service fee is a crucial factor. Therefore, we analyze the situation where the logistics service fee is exogenous first.

4.1 Given logistics service fee

Lemma 3 *Given logistics service fee, the equilibrium outcomes in Scenario S are:*

$\tilde{q}_A^S = \frac{2a-ab+bw}{4-b^2}$, $\tilde{q}_B^S = \frac{2a-ab-2w}{4-b^2}$, $\tilde{p}_A^S = \frac{a(2-b)+bw}{4-b^2}$, $\tilde{p}_B^S = \frac{a(b-2)+(b^2-2)w}{b^2-4}$, $\tilde{\pi}_A^S = \frac{a^2(2-b)^2+a(8-4b^2+b^3)w+(3b^2-8)w^2}{(4-b^2)^2}$, $\tilde{\pi}_B^S = \frac{(a(b-2)+2w)^2}{(4-b^2)^2}$.

The subscript "~" denotes the exogenous logistics service fee case. We restrict $w \in \left(0, \frac{a}{2}\right)$ to ensure all variables to be positive.

Proposition 1

(a) $\frac{\partial \tilde{q}_B^S}{\partial b} < 0$ *for all feasible b;*

(b) *If* $w \in \left(0, \frac{a}{5}\right)$, $\frac{\partial \tilde{q}_A^S}{\partial b} < 0$; *if* $w \in \left(\frac{a}{5}, \frac{a}{2}\right)$, $\frac{\partial \tilde{q}_A^S}{\partial b} < 0$ *when* $b \in \left(0, \frac{2(a-\sqrt{2aw-w^2})}{a-w}\right)$ *and* $\frac{\partial \tilde{q}_A^S}{\partial b} > 0$ *when* $b \in \left(\frac{2(a-\sqrt{2aw-w^2})}{a-w}, 1\right)$;

(c) $\frac{\partial \frac{\tilde{q}_A^S}{\tilde{q}_B^S}}{\partial b} > 0$ *for all feasible b.*

Proposition 1 (a) and (b) suggest that, given the logistics service fee, firm B's quantity in the end market is decreasing in *b* (market competition intensity degree) but when the logistics service fee and *b* is large, firm A's is increasing in *b*. (c) suggests that the market share of firm A becomes larger as *b* increases. We can regard the logistics service fee as firm B's cost disadvantage when he competes with firm A because firm A has zero cost and can control firm B's logistics cost. It's intuitive that a large *b* results in small $\tilde{q}_A^S$ and $\tilde{q}_B^S$. However, if *w* is high and *b* exceeds a threshold, we find that $\frac{\partial \tilde{q}_A^S}{\partial b} > 0$. That is because firm A's profit gains from logistics $w\tilde{q}_B^S$ is acceptable but constrained by decreasing $\tilde{q}_B^S$. Firm A tends to enhance her own product selling business by increasing $\tilde{q}_A^S$. As a result, firm A occupies a larger market, i.e., $\frac{\partial \frac{\tilde{q}_A^S}{\tilde{q}_B^S}}{\partial b} > 0$ and we denote $\frac{\tilde{q}_A^S}{\tilde{q}_B^S}$ as the *"monopoly effect"* (firm A controls all the logistics services).

Proposition 2 *Firm B's price is decreasing in b, i.e.,* $\frac{\partial \tilde{p}_B^S}{\partial b} < 0$*; firm B's total sales is decreasing in b, i.e.,* $\frac{\partial \tilde{q}_B^S \tilde{p}_B^S}{\partial b} < 0$ *and the profit allocation ratio (unit logistics fee)/(firm B's retail price) is increasing in b, i.e.,* $\frac{\partial \frac{w}{\tilde{p}_B^S}}{\partial b} > 0$.

First, the increase of competition intensity degree means the influence of one firm's quantity on the other one's price becomes more significant. As we discussed in Proposition 1, if *b* increases, although firm B has strong motivation to keep his price by decreasing the quantity, firm A's quantity doesn't decrease as much as firm B or even increases given a high *w* and large *b*. In this case, the logistics service fee *w* is a constant and firm B's price is decreasing in b, so the profit allocation ratio (unit logistics fee)/(firm B's retail price) is increasing in *b*. The total sales of firm B is divided by the ratio (unit logistics fee)/(firm B's retail price) and the larger the ratio is the more profits firm A will snatch.

4.2 Endogenous logistics service fee

Lemma 4 *When the logistics service fee is endogenous, our main results in proposition 1 and proposition 2 qualitatively hold, i.e.,* $\frac{\partial \frac{q_A^S}{q_B^S}}{\partial b} > 0$, $\frac{\partial q_B^S p_B^S}{\partial b} < 0$ *and* $\frac{\partial \frac{w^S}{p_B^S}}{\partial b} > 0$.

Proposition 3 *In Scenario S,* $\frac{\partial w^S}{\partial b} < 0$ *if* $b \in (0, b_1)$ *and* $\frac{\partial w^S}{\partial b} > 0$ *if* $b \in (b_1, 1)$.
Note that b_1 *satisfies* $16b_1 - 24{b_1}^2 + 3{b_1}^3 = 0$.

Proposition 3 indicates that, the logistics service fee is unimodal in *b*. When $b \in (0, b_1)$, as we discussed, firm A's market share and the proportion divided from *firm B's total sales* are increasing in *b*. However, *firm B's total sales* becomes smaller. When the logistics service fee is endogenous, firm A would choose to lower the logistics service fee if $b \in (0, b_1)$. The reasons are as follows: Firm A sets a low logistics service fee would mitigate the double marginalization effect, make the supply chain more efficient, and slow down the decrease of *firm B's total sales*.

Although a low logistics service fee may reduce the benefits of *"monopoly effect"*, we find that firm B's total sales is large enough, which benefits firm A even her proportion is small. When $b \in (b_1, 1)$, *firm B's total sales* becomes quite small and firm A's market share is quite large. Being aware of this, firm A pays attention to her product selling business and sets high logistics service fee to increase firm B's cost. This further increases firm A's market share and helps firm A divide a larger proportion of *firm B's total sales*. The logistics service fee would relatively low when *b* is in a moderate range.

Proposition 4 *Firm B* prefers *Scenario S* over *Scenario N* if and only if $l \in \left(l_0, \frac{a}{2}\right)$ and $b \in (b_2, b_3)$.

Note that l_0 *satisfies* $5a^3 - 90a^2 l_0 + 216a{l_0}^2 - 108{l_0}^3 = 0$, *and* b_2, b_3 *satisfy* $8a - 16l - (4a - 6l)b_i^2 + ab_i^3 = 0, i \in \{2,3\}$.

Proposition 4 shows (Figure 2) that firm B will use the sharing logistics services only if his delivery time disadvantage is significant enough and the competition intensity degree is in a moderate range. Given a low competition intensity degree, firm A and B are involved in a mild competition and the former's market share is small. If firm B joins firm A's LSA, his logistics service would be improved and that can further increase his sales. As mentioned in Proposition 3, firm A has incentives to charge a high unit logistics service fee to lower firm B's market share and generate more logistics service profits. Furthermore, this increases the double marginalization effect and leads to a relatively small total sales of firm B. In a word, firm B has the opportunity to generate more profits when competition is mild, but a large part of the profits is snatched by firm A through a high logistics service fee. And the total profits of the system also become small because of the double marginalization effect. In contrast, when the competition intensity degree is high, firm B's market share is extremely small because of a large *"monopoly effect"*. His logistics cost is also high due to firm A's high logistics service fee. Therefore, firm B's total sales quickly decreased. What's more, the profit allocation ratio is increasing in *b*, which means firm B can only divide a small proportion of his total sales. These negative forces eliminate firm B's willing to join firm A's LSA. Only when the competition intensity degree is in a moderate range, would the logistics service fee become low, which induces firm A to encourage firm B to increase demand size. Firm A has a satisfying market share and an acceptable proportion of firm B's total sales. These two firms reach an incentive alignment under LSA.

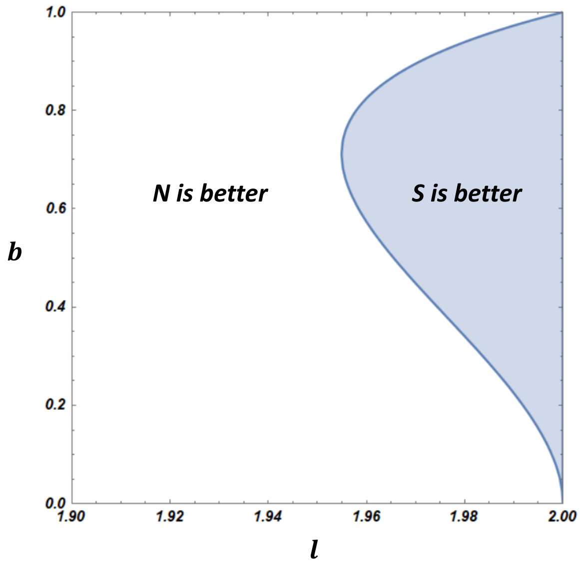

Figure 2. Firm B's preferences over LSA without PDT (a=4)

5 Extensions

5.1 PDT guarantee of firm B

In this extension, we consider another scenario where firm B guarantees a PDT while using its own logistics. We denote this scenario as Scenario N' and the event sequences are shown in Figure 3:

(1) Firm B chooses to join firm A's LSA or not.

(2) If firm B joins the LSA, firm A decides the logistics services fee. Then the two firms choose their quantities simultaneously. If firm B uses his own logistics and guarantee a PDT, firm A decides her quantity and at the same time firm B decides his PDT and quantity.

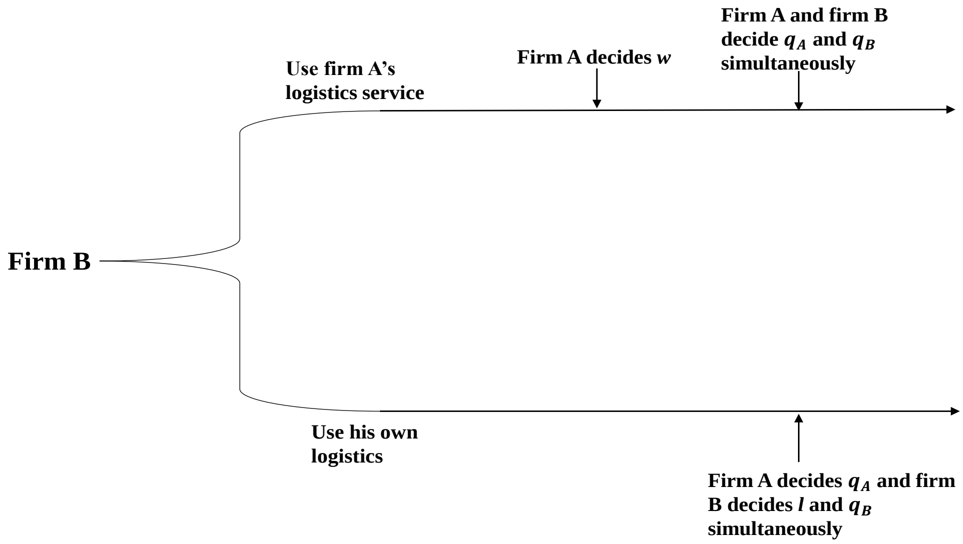

Figure 3. The event sequences

Although in this scenario firm B can decide the PDT, this will incur a marginal PDT cost c^L if the delivery is delayed. Before we derive the inverse demand functions and profit functions in Scenario N', we first analyze the PDT cost.

The realized delivery time (RDT) m is always random in real life and when the RDT exceeds the PDT l, the e-commerce firms should compensate for customers. We denote the compensation as the PDT cost and this cost only happens when the delivery is delayed. According to Liu et al. (2007), we see that firm B's RDT depends on his quantity q_B with cumulative distribution function (cdf) U_{q_B} and probability density function (pdf) u_{q_B}. Hence the marginal PDT cost function is:

$$c^L = c^T \int_l^{\infty} (m - l)\, dU_{q_B}(m)$$

The profit function of firm B in Scenario N' becomes:

$$\pi_B = \left(p_B - c^T \int_l^{\infty} (m - l)\, dU_{q_B}(m) \right) q_B$$

We solve the problem in Scenario N', and the following equation must be satisfied when firm B decides his quantity and PDT.

$$\frac{\partial \pi_B}{\partial l} = -c^T \left(U_{q_B}(l) - 1 \right) - 1 = 0$$

Then we have the optimal l given q_B as:

$$l^*(q_B) = U_{q_B}^{-1}\left(\frac{c^T - 1}{c^T} \right)$$

Following Liu et al. (2007), Wu et al. (2012) and Chen and Wu (2018), the RDT is $m = q_B v$, in which variable v has cdf $Z(v)$ and pdf $z(v)$. Then we denote $U_{q_B}(m) = Z\left(\frac{m}{q_B}\right)$ and $u_{q_B}(m) = z\left(\frac{m}{q_B}\right)/q_B$. As a result, the PDT cost is:

$$c^L = c^T \int_l^\infty (m-l) z\left(\frac{m}{q_B}\right) d\left(\frac{m}{q_B}\right)$$

Therefore, the inverse demand functions and profit functions are, respectively

$$p_A = a - q_A - bq_B$$

$$p_B = a - l - q_B - bq_A$$

$$\pi_A = p_A q_A$$

$$\pi_B = (p_B - c^L) q_B.$$

Note that, $U_{q_B}(m) = Z\left(\frac{m}{q_B}\right)$, we have $U_{q_B}^{-1}\left(\frac{c^T-1}{c^T}\right) = q_B Z^{-1}\left(\frac{c^T-1}{c^T}\right)$. Let $\beta = Z^{-1}\left(\frac{c^T-1}{c^T}\right)$, then the PDT becomes a function of q_B, $l^*(q_B) = \beta q_B$. The PDT cost can be written as

$$c^L = q_B c^T \int_\beta^\infty (y-\beta) z(y)\, dy$$

where $y = \frac{m}{q_B}$. It's obvious that $c^T \int_\beta^\infty (y-\beta) z(y)\, dy$ is a constant, so, we regard the PDT cost as a function of q_B:

$$c^L = \gamma q_B$$

where $\gamma = c^T \int_\beta^\infty (y-\beta) z(y)\, dy$.

Hence, the demand functions and profit functions in Scenario N' become:

$$p_A = a - q_A - bq_B$$

$$p_B = a - \beta q_B - q_B - bq_A$$

$$\pi_A = p_A q_A$$

$$\pi_B = (p_B - \gamma q_B) q_B.$$

Denote $\phi = (1 + \beta + \gamma) \in (1, +\infty)$. We have Lemma 5:

Lemma 5 *The equilibrium outcomes in Scenario N' are:*

$q_A^{N'} = \frac{a(b-2\phi)}{b^2-4\phi}$, $q_B^{N'} = \frac{a(2-b)}{4\phi-b^2}$, $\pi_A^{N'} = \frac{a^2(b-2\phi)^2}{(b^2-4\phi)^2}$, $\pi_B^{N'} = \frac{a^2(2-b)^2\phi}{(b^2-4\phi)^2}$.

Then we compare Scenario N' and Scenario S to analyze the impact of firm B's introducing PDT. We have Proposition 5 and 6.

Proposition 5

(a) When $\phi \in (4,\infty)$, $q_B^N - q_B^{N'} > 0$ *if* $b \in (0, b_5)$*;*

(b) $\frac{\partial \frac{q_B^N}{q_B^{N'}}}{\partial b} < 0$ *for all feasible values of b.*

Note that $b_5 = min\left[\frac{-2a+2a\phi-\sqrt{(2a-2a\phi)^2-4l(-4a+4a\phi-4l\phi)}}{2l}, 1\right]$.

In order to figure out the difference when firm B guarantees a PDT, we compare firm B's quantity with and without PDT. Our intuition is that when the competition intensity degree is low, firm B has strong incentives to set a large quantity in both cases (with and without PDT). However, when there is a PDT, firm B's realized delivery time is closely related to the workload, q_B. Given a large quantity, the realized delivery time may exceed the PDT frequently, which leads to a huge delay cost. These restrict firm B's incentives to set a large quantity. As a result, when ϕ is large and b is small, firm B's quantity is lower with PDT. Proposition 5 (b) means the gap between q_B^N and $q_B^{N'}$, which becomes smaller as b increases. The reason is that, when the competition intensity degree is high, firm B's incentives to have a large quantity would be increased, which softens the restriction of firm B's quantity from PDT. We denote $\frac{q_B^N}{q_B^{N'}}$ as an index of the "restrict effect", which reflects the degree of the PDT's restriction on firm B's quantity.

Proposition 6 *Firm B prefers Scenario S over Scenario N' if and only if* $\phi \in (4, +\infty)$ *and* $b \in (0, b_6)$.

Note that b_6 *uniquely satisfies* $256\phi - 64\phi^2 - (256\phi - 128\phi^2)b_6 - (96\phi + 64\phi^2){b_6}^2 + 128\phi {b_6}^3 - (4 - 20\phi){b_6}^4 + (8 - 36\phi){b_6}^5 - (4 - 9\phi){b_6}^6 = 0$.

Compared with Proposition 4, the key difference is that, when *b* is small, firm B tends to join firm A's LSA. The main reason is the *"restrict effect"* we have mentioned above: Firm B's delivery time is related to the quantity (logistics service workload). And large quantity would lead to a long delivery time, which results in a large delay cost. We illustrate the *"restrict effect"* in Figure 4. When *b* is small, the *"restrict effect"* is quite strong and firm B's quantity is restricted to a small level. This increases firm A's incentives to charge a low logistics service fee, which stimulates firm B's order size. Therefore, firm A's pricing power is constrained, too. Given the improved logistics service level and the enlarged market potential, firm B has the incentives to join LSA.

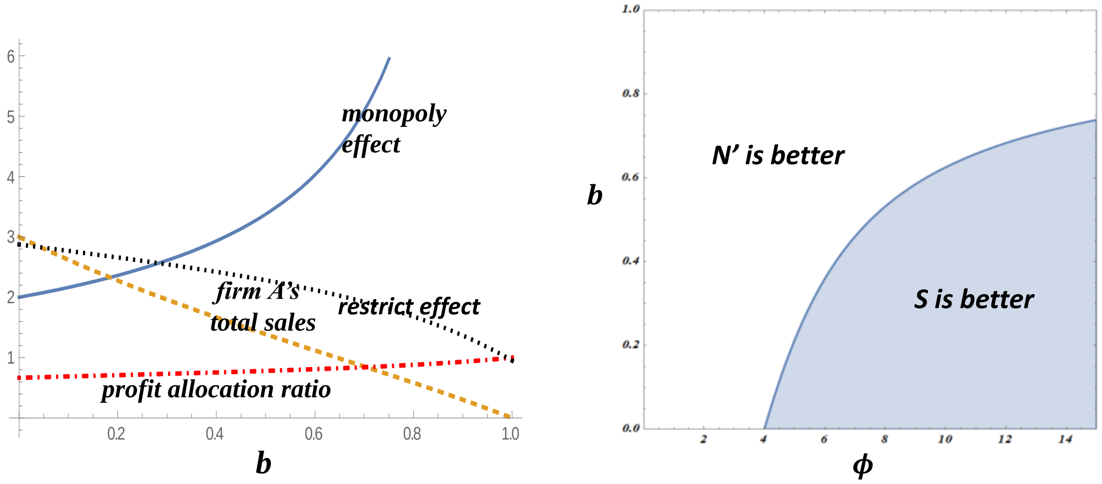

Figure 4. Firm B's total sales, firm B's profit allocation ratio, the monopoly effect and the restrict effect with b (left) (a=4, ϕ=5, l=1.7); firm B's preferences over LSA with PDT (right) (a=4)

5.2 Firm B's logistics service cost

In the main body, firm A and B's costs of their logistics service are normalized to zero. However, in practice, both JD and Tootoo have logistics service costs and it's well known that JD has utilized smart logistics system which is efficient to lower the cost. Therefore, we assume firm A and B's logistics service costs are c_A and c_B, respectively, and $c_A < c_B$. The profit functions are:

In Scenario N,

$$\pi_A = (p_A - c_A)q_A,$$

$$\pi_B = (p_B - c_B)q_B;$$

In Scenario S,

$$\pi_A = (p_A - c_A)q_A + (w - c_A)q_B,$$

$$\pi_B = (p_B - w)q_B.$$

For model tractability, we define $c = c_B - c_A$ which represents the cost difference between firm A and firm B and we assume $c_A = 0$. The profit functions are changed to:

In Scenario N,

$$\pi_A = p_A q_A,$$

$$\pi_B = (p_B - c) q_B;$$

In Scenario S,

$$\pi_A = p_A q_A + w q_B,$$

$$\pi_B = (p_B - w) q_B.$$

Solving the problems by backward induction, we have Lemma 6 and Lemma 7. We use superscripts on the optimums: NC and SC denote Scenario N and Scenario S. We assume $0 < c < \frac{2a-ab-2l}{2}$ to ensure all variables are positive.

Lemma 6 *The equilibrium outcomes in Scenario N are*

$q_A^{NC} = \frac{2a-ab+bc+bl}{4-b^2}$, $q_B^{NC} = \frac{2a-ab-2c-2l}{4-b^2}$, $\pi_A^{NC} = \frac{(a(-2+b)-b(c+l))^2}{(4-b^2)^2}$, $\pi_B^{NC} = \frac{(a(-2+b)+2(c+l))^2}{(4-b^2)^2}$.

Lemma 7 *The equilibrium outcomes in Scenario S are*

$q_A^{SC} = \frac{a(2-b)(4+b)}{16-6b^2}$, $q_B^{SC} = \frac{2a(1-b)}{8-3b^2}$, $w^{SC} = \frac{a(8-4b^2+b^3)}{16-6b^2}$, $\pi_A^{SC} = \frac{a^2(12-8b+b^2)}{4(8-3b^2)}$, $\pi_B^{SC} = \frac{4a^2(1-b)^2}{(8-3b^2)^2}$.

Then we investigate how firm B's incentive of joining LSA changes. The results are summarized in Proposition 7.

Proposition 7 *Firm B prefers scenario S if and only if one of the following conditions is satisfied:*

(i) $l \geqslant l_0^C$;

(ii) $l < l_0^C$ *and* $c > c_0$.

Note that $l_0^C = \frac{(8-4b^2+b^3)a}{16-6b^2}$ *and* $c_0 = \frac{-8a+4ab^2-ab^3+16l-6b^2l}{-16+6b^2}$.

Proposition 7 illustrates that, when firm B's logistics service disadvantage is sufficiently large (i.e., $l \geqslant l_0^C$), regardless of his logistics service cost, firm B would join the LSA. In the situation where firm B's logistics service disadvantage is small, it's in line with our intuition that when his logistics cost is high, firm B would join the LSA.

To figure out the differences of the results with and without logistics service cost, we conduct extensive numerical studies, and the representative curves are illustrated in Figure 5.

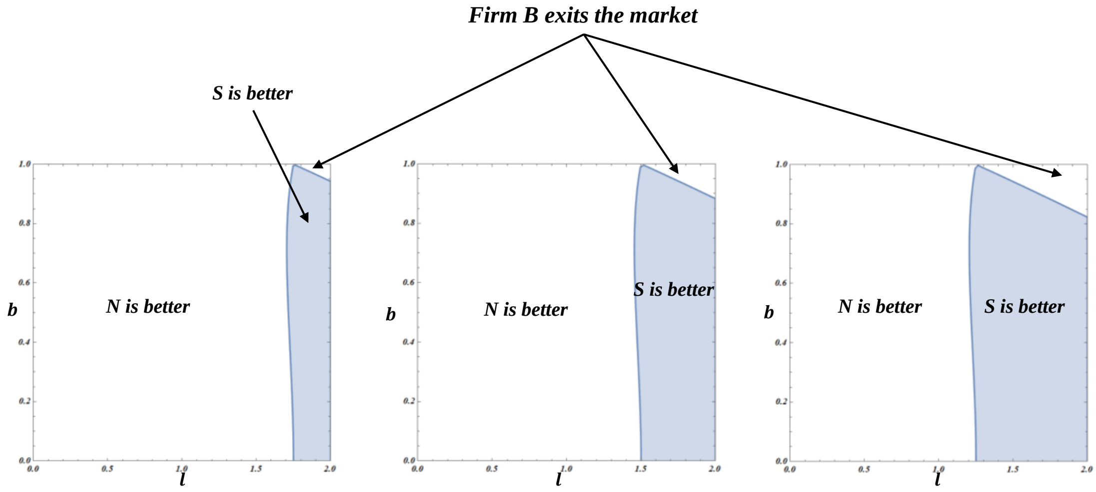

Figure 5. Firm B's preferences over LSA considering logistics service cost difference (a=4)

Lemma 8 *When there is a logistics service cost difference,*

(a) firm A's quantity increases while firm B's quantity decreases in the logistics service cost difference, i.e., $\frac{\partial q_A^{NC}}{\partial c} > 0$ *and* $\frac{\partial q_B^{NC}}{\partial c} < 0$*;*

(b) both firm A and firm B's prices increase in the logistics service cost difference, i.e., $\frac{\partial p_A^{NC}}{\partial c} > 0$ *and* $\frac{\partial p_B^{NC}}{\partial c} > 0$*;*

(c) both firm A and firm B's prices decrease in the competition intensity degree, i.e., $\frac{\partial p_A^{NC}}{\partial b} < 0$ *and* $\frac{\partial p_B^{SC}}{\partial b} < 0$*.*

Comparing the results in Proposition 7 (see Figure 5) with Proposition 4 (see Figure 2), we find that, when there is a logistics service cost difference between two firms, firm B's incentive to join LSA is significantly increased. As the cost difference becomes larger, firm B has more incentives to join LSA. According to Lemma 8 (a), when the cost difference increases, firm A's quantity increases while firm B's quantity decreases. In other words, a large cost difference constrains firm B's incentives to decide a large quantity and makes firm A occupy a larger market share. Lemma 8 (b) shows that, both the firms' prices increase in c. However, the increase of firm B's price can't compensate the loss because of a higher logistics service cost and a smaller quantity. As a result, the logistics service cost difference makes firm B worse off in Scenario N.

Besides, we find the logistics service cost difference may expel firm B out of the market when both competition intensity degree and his logistics service disadvantage are significant. As shown in Lemma 8 (c), when the competition intensity degree becomes larger, the prices of firm B's products become lower. A large logistics service disadvantage leads to a small market potential which further lowers firm B's prices. Therefore, firm B is expelled out of the market.

5.3 Revenue-sharing between firm A and firm B

We observe that, revenue-sharing contracts are widely used between JD stores and JD, where JD stores refer to the e-commerce firms that sell products on JD.com, like Tootoo flagship store. It is possible that Tootoo opens a store on JD.com. Thus, we are interested in how will firm A and B's decisions of LSA change with a revenue-sharing contract. We denote the scenario where firm B joins firm A's LSA as Scenario S and the scenario firm B doesn't join the LSA as Scenario N.

Their profit functions in Scenario N and S are:

In Scenario N,

$$p_A = a - q_A - bq_B$$

$$p_B = a - l - q_B - bq_A$$

$$\pi_A = p_A q_A + rp_B q_B$$

$$\pi_B = (1-r)p_B q_B.$$

In Scenario S,

$$p_A = a - q_A - bq_B$$

$$p_B = a - q_B - bq_A$$

$$\pi_A = p_A q_A + rp_B q_B + wq_B$$

$$\pi_B = (1-r)p_B q_B - wq_B.$$

$r \in (0,1)$ represents the revenue-sharing rate charged by firm A and we assume $l \in \left(0, \frac{a}{2}\right)$ to ensure all variables to be positive. We solve the problems by backward induction and equilibrium outcomes are summarized in Lemma 9 and 10. We incorporate superscripts on the optimums: NR and SR denote Scenario N and Scenario S.

Lemma 9 *The equilibrium outcomes under a revenue-sharing contract in Scenario N are:*

$$q_A^{NR} = \frac{(1+r)bl+(2-b-br)a}{4-(1+r)b^2},\ q_B^{NR} = \frac{(2-b)a-2l}{4-(1+r)b^2},$$

$$\pi_A^{NR} = \frac{(1+r)(4a^2-4a^2b+4abl+a^2b^3r-ab^3lr)+2ab^2l(-1+r^2)-a^2b^2(-1+r+r^2)+l^2(4r-b^2(-1+r^2))-8alr}{(4-b^2(1+r))^2},$$

$$\pi_B^{NR} = \frac{(a(-2+b)+2l)^2(1-r)}{(4-b^2(1+r))^2}.$$

Lemma 10 *The equilibrium outcomes under a revenue-sharing contract in Scenario S are:*

$$w^{SR} = \frac{a(-1+r)(8(-1+r)-4br+b^2(4+2r-2r^2)+b^3(-1+r^2))}{2(8-4r+b^2(-3-2r+r^2))}, q_A^{SR} = \frac{a(8-4r-2b(1+r)-b^2(1-r^2))}{2(8-4r-b^2(3+2r-r^2))},$$

$$q_B^{SR} = \frac{2a(1-b)}{8-4r-b^2(3+2r-r^2)},\ \pi_A^{SR} = \frac{a^2(4(3-r)+b^2(1-r)^2-8b)}{4(8-4r-b^2(3+2r-r^2))},\ \pi_B^{SR} = \frac{4a^2(1-b)^2(1-r)}{(8-4r-b^2(3+2r-r^2))^2}.$$

Then we compare firm B's profits in Scenario S and N.

Proposition 8 *Under a revenue-sharing contract, firm B prefers Scenario S over Scenario N if and only if* $l > l_0^R$.

Note that, $l_0^R = \frac{8a-4ab^2+ab^3-8ar+4abr-2ab^2r+2ab^2r^2-ab^3r^2}{16-6b^2-8r-4b^2r+2b^2r^2}$.

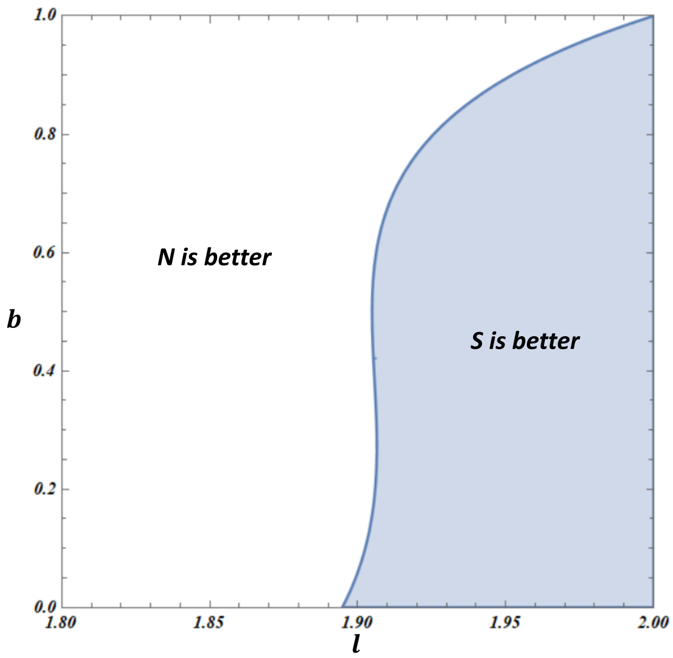

Figure 6. Firm B's preferences over LSA under a revenue-sharing contract (*r=0.1, a=4*)

We illustrate Proposition 8 using Figure 6. We find that, when firm A and B sign a revenue-sharing contract, firm B would join firm A's LSA if his delivery time disadvantage is sufficiently large. In addition, as b increases, firm B's incentive to join LSA is reduced (the blue area becomes smaller in Figure 6). One may expect that, when there is a revenue-sharing contract between two firms, firm B will be at a more disadvantageous position if he joins firm A's LSA. However, comparing this result (Figure 6) to that in Proposition 4 (Figure 2), we find a revenue-sharing contract greatly increases firm B's incentives to join LSA, especially when the competition intensity degree is low. In order to figure out the underlying reasons, we have Lemma 11.

Lemma 11 *When there is a revenue-sharing contract between firm A and B,*

(a) $\frac{\partial \frac{q_A^{SR}}{q_B^{SR}}}{\partial b} > 0, \ \frac{\partial q_B^{SR} p_B^{SR}}{\partial b} < 0 \ \textit{and} \ \frac{\partial \frac{w^{RS}}{p_B^{SR}}}{\partial b} > 0;$

(b) $\frac{\partial \frac{q_A^{SR}}{q_B^{SR}}}{\partial r} < 0, \ \frac{\partial q_B^{SR} p_B^{SR}}{\partial r} > 0 \ \textit{and} \ \frac{\partial \frac{w^{RS}}{p_B^{SR}}}{\partial r} < 0;$

(c) $w^{\text{RS}} < w^S;$

(d) $\frac{\partial w^{\text{RS}}}{\partial r} < 0;$

(e) $\frac{\partial w^{\text{RS}}}{\partial b} > 0 \ \textit{if} \ b \in (0, b_4) \cup (b_5, 1) \ \textit{and} \ \frac{\partial w^{\text{RS}}}{\partial b} < 0 \ \textit{if} \ b \in (b_4, b_5).$

Note that, b_4, b_5 *uniquely satisfy* $16(-2+r)r + 16b_i(1+r) + {b_i}^4(1+r)^2(3-4r+r^2) - 8{b_i}^2(3-2r^2+r^3) = 0, \ i \in \{4,5\}.$

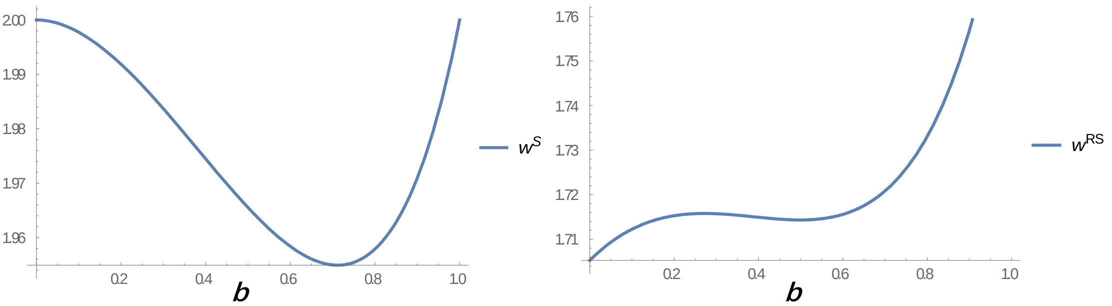

Figure 7. The wholesale price in Scenario S with (left) and without (right) revenue-sharing contract (*a=4, r=0.1*).

Lemma 11 (a) shows that, when there is a revenue-sharing contract between firm A and B, our main results in proposition 1 and proposition 2 qualitatively hold. However, Lemma 11 (b) demonstrates some interesting results that the *"monopoly effect"* decreases in the revenue-sharing ratio *r*, *"firm B's total sales"* increases in *r* and *"the allocation ratio"* decreases in *r*. These results indicate that, the revenue-sharing contract leads to firm B's larger market share, larger total revenue and larger profit allocation ratio. Therefore, the revenue-sharing contract strengthens the positive forces and weakens the negative forces for firm B. Further investigating the wholesale price, as shown in Lemma 11 (c), we find the logistics service fee in Scenario S under a revenue-sharing contract is lower than that without a revenue-sharing contract. Lemma 11 (d) indicates that the logistics service fee under a revenue-sharing contract decreases in r. Recall that, when there is no revenue-sharing contract, firm A has the flexibility to balance her profits between downstream market revenue and logistics service fee. When there is a revenue-sharing contract, firm A has one more revenue resource, the revenue-sharing part from firm B. One might expect that this will make firm B worse. However, this protects firm B's downstream revenue to some extent because of a lower logistics service fee. Firm A actually emphasizes the shared profit from firm B and their profits are aligned better.

Lemma 11 (e) shows the logistics service fee decreases in b when b is in a moderate range. Otherwise it increases in b. As Figure 7 shows, comparing the logistics service fees with and without revenue-sharing contract, we find that, when b is small, the logistics service fee drops to a very low level under a revenue-sharing contract. A small b means the interaction between two firms is weak, and firm A can charge a very low logistics service fee to stimulate firm B's quantity. That leads to a win-win situation where firm A's profits are relatively high and firm B benefits from firm A's lower logistics fee. This is the key reason that firm B's incentive to join LSA is increased, especially when the competition intensity degree is small. Possible managerial enlightenment is that, the revenue-sharing contract can mitigate the conflicts between firms like JD and Tootoo, and increase their possibility of cooperation using LSA.

6 Conclusion

Customers have witnessed more and more sales of "product + logistics" in the e-commerce era. Firms having logistics advantages hence have the opportunities to generate profits by providing logistics sharing services to the rivals. However, horizontal cooperation can strategically influence the competition. The rivals' incentives to join LSA hence becomes a strategic decision too. In this paper, we formulate an e-commerce firm having logistics disadvantages and his tradeoffs to join LSA, with and without PDT consideration.

We characterize the outcomes in a co-opetitive supply chain if LSA agreement is reached. We find firm B benefits from using a better logistics service offered by firm A when their products competition intensity degree is in a moderate range. It is surprising that when competition intensity degree is low, firm B should not join firm A's LSA. When the competition intensity degree is low, firm B faces mild competition from firm A, and the latter's market share is small because of the "monopoly effect". Joining firm A's LSA helps firm B improve logistics services and hence, further increases sales. That induces firm A to charge a high logistics service fee, which results a larger double marginalization effect and a system profit loss. This explains why firm B should not join firm A's LSA given a low competition intensity degree. We also find that, a PDT changes firm B's choice when the competition intensity degree is low. That is, firm B would join firm A's LSA because PDT restricts firm B's quantity and hence, indirectly constrains firm B's pricing power when she determines the logistics service fee.

We discuss two future research directions. First, we have assumed firm A has the full pricing power to determine the logistics service fee. In practice, this fee can be negotiable using a bargaining framework. That might constrain firm A's profits and induces firm B to join LSA. Second, firm A and B might outsource the logistics services to third party logistics companies. The impact of spot logistics services can be interesting but is beyond the scope of this paper.

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Appendix

Proof of proposition 1.

The derivations of $\tilde{q}_B^S$, $\tilde{q}_A^S$ and $\frac{\tilde{q}_A^S}{\tilde{q}_B^S}$ with respect to b are

$$\frac{\partial \tilde{q}_B^S}{\partial b} = -\frac{a(2-b)^2 + 4bw}{(4-b^2)^2} < 0$$

$$\frac{\partial \tilde{q}_A^S}{\partial b} = \frac{-a(-2+b)^2 + (4+b^2)w}{(-4+b^2)^2}$$

$$\frac{\partial \frac{\tilde{q}_A^S}{\tilde{q}_B^S}}{\partial b} = \frac{2(2a-w)w}{(a(-2+b)+2w)^2} > 0$$

Solving the equation $-a(-2+b)^2 + (4+b^2)w = 0$, we have $b = \frac{2(a-\sqrt{2aw-w^2})}{a-w}$. Clearly, $\frac{2(a-\sqrt{2aw-w^2})}{a-w} > 1$ if $w \in \left(0, \frac{a}{5}\right)$ and $\frac{2(a-\sqrt{2aw-w^2})}{a-w} < 1$ otherwise. Therefore, when $w \in \left(\frac{a}{5}, \frac{a}{2}\right)$, we have $\frac{\partial \tilde{q}_A^S}{\partial b} < 0$ if $b \in \left(0, \frac{2(a-\sqrt{2aw-w^2})}{a-w}\right)$. Otherwise, we have $\frac{\partial \tilde{q}_A^S}{\partial b} > 0$ given $b \in \left(\frac{2(a-\sqrt{2aw-w^2})}{a-w}, 1\right)$.

Proof of proposition 2.

The first-order derivatives of $\tilde{p}_B^S$, $\tilde{q}_B^S\tilde{p}_B^S$ and $\frac{w}{\tilde{p}_B^S}$ are

$$\frac{\partial \tilde{p}_B^S}{\partial b} = -\frac{a(2-b)^2 + 4bw}{(4-b^2)^2} < 0$$

$$\frac{\partial \tilde{q}_B^S\tilde{p}_B^S}{\partial b} = \frac{2a^2(-2+b)^3 + ab(-16+12b-4b^2+b^3)w + 4b^3w^2}{(4-b^2)^3}$$

$$\frac{\partial \frac{w}{\tilde{p}_B^S}}{\partial b} = \frac{w(a(-2+b)^2 + 4bw)}{(a(-2+b)+(-2+b^2)w)^2} > 0$$

Clearly, we have $\frac{\partial \tilde{p}_B^S}{\partial b} < 0$ and $\frac{\partial \frac{w}{\tilde{p}_B^S}}{\partial b} > 0$. The sign of $\frac{\partial \tilde{q}_B^S\tilde{p}_B^S}{\partial b}$ is the same with $2a^2(-2+b)^3 + ab(-16+12b-4b^2+b^3)w + 4b^3w^2$. Rewrite it into a function of w:

$$h(w) = 4b^3w^2 + ab(-16+12b-4b^2+b^3)w + 2a^2(-2+b)^3$$

The signs of the coefficients are:

$$4b^3 > 0$$

$$ab(-16+12b-4b^2+b^3) < 0$$

$$2a^2(-2+b)^3 < 0$$

We require $h\left(\frac{a}{2}\right) < 0$ to guarantee $h(w) < 0$. Then we compute $h\left(\frac{a}{2}\right) = \frac{1}{2}a^2(-32+32b-12b^2+2b^3+b^4) < 0$, for $b \in (0,1)$. As a result, $\frac{\partial \tilde{q}_B^S\tilde{p}_B^S}{\partial b} < 0$.

Proof of proposition 3.

$$\frac{\partial w}{\partial b}=-\frac{ab(16-24b+3b^3)}{2(8-3b^2)^2}$$

The sign of $\frac{\partial w}{\partial b}$ depends on the sign of $16-24b+3b^3$. The first-order derivative is $-24+9b^2$, and it's negative when $b\in(0,1)$. As a result, $16-24b+3b^3$ is decreasing in *b* when $b\in(0,1)$. We have $(16-24b+3b^3)|_{b=0}=16$ and $(16-24b+3b^3)|_{b=1}=-5$. That suggest that there would be a b_1 satisfying $16-24b_1+3{b_1}^3=0$. When $b\in(0,b_1), \frac{\partial w}{\partial b}<0$; when $b\in(b_1,1), \frac{\partial w}{\partial b}>0$.

Proof of Lemma 4.

$$\frac{\partial\frac{q_A^S}{q_B^S}}{\partial b}=\frac{6-2b+b^2}{4(1-b)^2}>0$$

$$\frac{\partial q_B^S p_B^S}{\partial b}=\frac{a^2(128-144b+24b^2+32b^3-15b^4)}{(-8+3b^2)^3}$$

$$\frac{\partial\frac{w}{p_B^S}}{\partial b}=-\frac{4(-8+8b-7b^2+2b^3)}{(12-4b-4b^2+b^3)^2}$$

The signs of $\frac{\partial q_B^S p_B^S}{\partial b}$ and $\frac{\partial\frac{w}{p_B^S}}{\partial b}$ depend on $(128-144b+24b^2+32b^3-15b^4)$ and $(-8+8b-7b^2+2b^3)$. The first-order and second-order derivations of $(128-144b+24b^2+32b^3-15b^4)$ are $(-144+48b+96b^2-60b^3)$ and $(48+192b-180b^2)$. $(48+192b-180b^2)$ is positive and hence, $(-144+48b+96b^2-60b^3)$ is increasing in *b*. Because $(-144+48b+96b^2-60b^3)|_{b=1}=-60<0$, $(128-144b+24b^2+32b^3-15b^4)$ is decreasing in *b*. Then we compute minimum value of $(128-144b+24b^2+32b^3-15b^4)$ when *b*= 1: $(128-144b+24b^2+32b^3-15b^4)|_{b=1}=25>0$. So, $(128-144b+24b^2+32b^3-15b^4)>0$ for all feasible $b\in(0,1)$. Similarly, we have $(-8+8b-7b^2+2b^3)<0$ for all feasible $b\in(0,1)$. Therefore, $\frac{\partial q_B^S p_B^S}{\partial b}<0$ and $\frac{\partial\frac{w}{p_B^S}}{\partial b}>0$.

Proof of proposition 4.

The difference between π_B^S and π_B^N is

$$\pi_B^S-\pi_B^N=\frac{4a^2(1-b)^2}{(8-3b^2)^2}-\frac{(-a(2-b)+2l)^2}{(4-b^2)^2}$$

$$= \frac{-(8a - 4ab^2 + ab^3 - 16l + 6b^2l)(24a - 16ab - 8ab^2 + 5ab^3 - 16l + 6b^2l)}{(4 - b^2)^2(8 - 3b^2)^2}$$

Then we change it to

$$\pi_B^S - \pi_B^N = \frac{-f(b)g(b)}{(4 - b^2)^2(8 - 3b^2)^2}$$

in which $f(b) = (8a - 4ab^2 + ab^3 - 16l + 6b^2l)$ and $g(b) = 24a - 16ab - 8ab^2 + 5ab^3 - 16l + 6b^2l$. The sign of $(\pi_B^S - \pi_B^N)$ depends on the signs of $f(b)$ and $g(b)$.

The first-order-conditions (FOCs) of $f(b)$ with respect to *b* is

$$f'(b) = 3ab^2 - (8a - 12l)b$$

Solving the equation $f'(b) = 0$, there are two roots: 0 and $\frac{4(2a-3l)}{3a}$.

$$b_1 = 0$$

$$b_2 = \frac{4(2a - 3l)}{3a}$$

Comparing $b_2 = \frac{4(2a-3l)}{3a}$ with 1, we have two cases

$$\begin{cases} \dfrac{4(2a - 3l)}{3a} - 1 > 0, & l \in \left(0, \dfrac{5}{12}a\right) \quad (1) \\ \dfrac{4(2a - 3l)}{3a} - 1 < 0, & l \in \left(\dfrac{5}{12}a, \dfrac{1}{2}a\right) \quad (2) \end{cases}$$

In case (1), $f'(b)$<0 for all feasible $b \in (0,1)$, which means $f(b)$ is decreasing in *b*. We have $f(b) \geqslant f(1)$= $5a - 10l$>0.

In case (2), $f'(b)$ is negative first and then becomes positive, that is to say, $f(b)$ is decreasing in b first and then increasing in b. The sign of $f(b)$ depends on the value of $[f(b)]_{\min}$.

$$[f(b)]_{\min} = f\left(\frac{4(2a - 3l)}{3a}\right) = -\frac{8(5a^3 - 90a^2l + 216al^2 - 108l^3)}{27a^2}$$

Change it to

$$[f(b)]_{\min} = -\frac{8h(l)}{27a^2}$$

in which $h(l) = 5a^3 - 90a^2l + 216al^2 - 108l^3$. If $[f(b)]_{\min} > 0$, $f(b) > 0$ for all feasible $b \in (0,1)$, otherwise $f(b) > 0$ only when *b* is in a moderate range. Take the FOCs of $h(l)$ with respect to l.

$$h'(l) = -324l^2 + 432al - 90a^2$$

Solve the equation $h'(l) = 0$:

$$l_1 = \frac{1}{6}\left(4a - \sqrt{6}a\right), l_2 = \frac{1}{6}(4a + \sqrt{6}a)$$

Comparing l_1 and l_2 with $\frac{a}{2}$, we have $0 < l_1 < \frac{a}{2} < l_2$. $h(l)$ is decreasing in l if $l \in (0, l_1)$ and increasing in l otherwise, as a result, the minimum value of $h(l)$ is

$$[h(l)]_{\min} = h\left(\frac{1}{6}\left(4a - \sqrt{6}a\right)\right) = 3\left(3 - 2\sqrt{6}\right)a^3 < 0$$

And the values at endpoints are

$$h(0) = 5a^3 > 0$$

$$h\left(\frac{a}{2}\right) = \frac{a^3}{2} > 0$$

In contrary, $[f(b)]_{\min} = -\frac{8h(l)}{27a^2}$ is increasing in l if $l \in (0, l_1)$ and decreasing in l otherwise. It reaches the maximum when $h(l)$ reaches the minimum. Substituting $[h(l)]_{\min}$ into $[f(b)]_{\min}$, we have

$$\{[f(b)]_{\min}\}_{\max} = \frac{8}{9}(2\sqrt{6} - 3)a > 0$$

And the endpoints value of $[f(b)]_{\min}$ are

$$\{[f(b)]_{\min}\}|_{l=0} = -\frac{40a}{27} < 0$$

$$\{[f(b)]_{\min}\}|_{l=\frac{a}{2}} = -\frac{4a}{27} < 0$$

Clearly, $[f(b)]_{\min}$ changes from a negative value to positive and then decreases to a negative value again with l increasing from 0 to $\frac{a}{2}$. There exist two thresholds l_3, l_4 which satisfy $5a^3 - 90a^2l + 216al^2 - 108l^3 = 0$ and $0 < l_3 < l_1 < l_4 < \frac{a}{2} < l_2$. When $l \in (l_3, l_4)$, $[f(b)]_{\min} > 0$. And when $l = \frac{5a}{12}$, $[f(b)]_{\min} = \frac{5a}{6}$, which means $l_1 < \frac{5a}{12} < l_4$. In case (2): $l \in (\frac{5a}{12}, l_4)$, $[f(b)]_{\min} > 0$; $l \in (l_4, \frac{a}{2})$, $[f(b)]_{\min} < 0$.

Because $f(0)= 8a - 16l > 0$ and $f(1)= 5a - 10l > 0$, only when $[f(b)]_{\min} < 0$, would $f(b) < 0$. Letting $l_0 = l_4$, when $l \in \left(l_0, \frac{a}{2}\right)$, $[f(b)]_{\min} < 0$ and we have the following result: there exist two thresholds b_2 and b_3 which satisfy $f(b) = 0$, $f(b) < 0$ for $b \in (b_2, b_3)$.

Take the derivatives of $g(b)$ with respect to b

$$g'(b) = 15ab^2 + (12l - 16a)b - 16a$$

Solve the equation $g'(b) = 0$

$$b_1 = \frac{2(4a - 3l - \sqrt{76a^2 - 24al + 9\Delta^2})}{15a}$$

$$b_2 = \frac{2(4a - 3l + \sqrt{76a^2 - 24al + 9l^2})}{15a}$$

Comparing b_1 and b_2 with the thresholds 0 and 1, we have $b_1 < 0$ and $b_2 > 1$. So $g'(b) < 0$ for all feasible *b* and $g(b)$ is decreasing in *b*. Then we compute $[g(b)]_{\min} = g(1) = 5a - 10l > 0$. As a result of that, $g(b)$ is always positive for $b \in (0,1)$. The sign of $f(b)$ has been proved above. So $\pi_B^S - \pi_B^N > 0$ if and only if $l \in \left(l_0, \frac{a}{2}\right)$ and $b \in (b_2, b_3)$.

Proof of proposition 5.

$$q_B^N - q_B^{N'} = \frac{lb^2 + (2a - 2a\phi)b - 4a + 4a\phi - 4l\phi}{(-2+b)(2+b)(b^2 - 4\phi)}$$

Clearly, $(-2+b)(2+b)(b^2 - 4\phi) > 0$, we just need to judge the sign of $lb^2 + (2a - 2a\phi)b - 4a + 4a\phi - 4l\phi$. Let $K(b) = lb^2 + (2a - 2a\phi)b - 4a + 4a\phi - 4l\phi$ and $K(b)$ is a quadratic function. If $\phi \in (4, \infty)$, the signs of the coefficients are:

$$l > 0$$

$$(2a - 2a\phi) < 0$$

$$4a\phi - 4l\phi - 4a > 0$$

We compare 1 with the function of aixs of symmetry, $-\frac{(2a-2a\phi)}{2l} - 1 > 0$. So, there would be two cases:

(1) If $K(1) > 0$, $q_B^N - q_B^{N'} > 0$ for all feasible *b*.

(2) If $K(1) < 0$, when $b \in (0, \frac{-2a+2a\phi-\sqrt{(2a-2a\phi)^2-4l(-4a+4a\phi-4l\phi)}}{2l})$, $q_B^N - q_B^{N'} > 0$; otherwise, $q_B^N - q_B^{N'} < 0$, where $\frac{-2a+2a\phi-\sqrt{(2a-2a\phi)^2-4l(-4a+4a\phi-4l\phi)}}{2l} < 1$.

As a result, $q_B^N - q_B^{N'} > 0$, if $b \in (0, b_5)$. Where

$$b_5 = \min\left[\frac{-2a+2a\phi-\sqrt{(2a-2a\phi)^2-4l(-4a+4a\phi-4l\phi)}}{2l}, 1\right].$$

Proof of proposition 6.

$$\pi_B^S - \pi_B^{N'} = \frac{b^6(4-9\phi) + 4b^5(-2+9\phi) + b^4(4-20\phi) - 128b^3\phi + 32b^2\phi(3+2\phi) - 128b(-2+\phi)\phi + 64(-4+\phi)\phi}{(-8+3b^2)^2(b^2-4\phi)^2}$$

Change it to

$$\pi_B^S - \pi_B^{N'} = \frac{I(b)}{(-8+3b^2)^2(b^2-4\phi)^2}$$

in which

$$I(b) = b^6(4-9\phi) + 4b^5(-2+9\phi) + b^4(4-20\phi) - 128b^3\phi + 32b^2\phi(3+2\phi)$$
$$-128b(-2+\phi)\phi + 64(-4+\phi)\phi$$

Because $(-8+3b^2)^2(b^2-4\phi)^2 > 0$, the sign of $\pi_S^N - \pi_A^{N'}$ depends on the sign of $I(b)$. Take the derivatives of $I(b)$ with respect to b

$$I'(b) = 4b^3(4-20\phi) + 6b^5(4-9\phi) - 384b^2\phi - 128(-2+\phi)\phi$$
$$+64b\phi(3+2\phi) + 20b^4(-2+9\phi)$$

$$I^{(2)}(b) = 12b^2(4-20\phi) + 30b^4(4-9\phi) - 768b\phi + 64\phi(3+2\phi) + 80b^3(-2+9\phi)$$

$$I^{(3)}(b) = 24b(4-20\phi) + 120b^3(4-9\phi) - 768\phi + 240b^2(-2+9\phi)$$

$$I^{(4)}(b) = 24(4-20\phi) + 360b^2(4-9\phi) + 480b(-2+9\phi)$$

We can infer that when b increases from 0 to 1, $I^{(4)}(b)$ changes from negative to positive and $I^{(3)}(b) < 0$ for all feasible b. As a result, $I^{(2)}(b)$ is decreasing in b. Compute $I^{(2)}(0) = 64\phi(3+2\phi) > 0$ and $I^{(2)}(1) = 8 - 366\phi + 128\phi^2$, so the sign of $I^{(2)}(b)$ depends on the sign of $I^{(2)}(1)$. There are two cases: (1) $\phi \in \left(1, \frac{1}{128}\left(183+\sqrt{32465}\right)\right)$, $I^{(2)}(1) < 0$. (2) $\phi \in \left(\frac{1}{128}\left(183+\sqrt{32465}\right), \infty\right)$, $I^{(2)}(1) > 0$. By knowing the increase-decrease characteristics of $I'(b)$, we derive the sign of $I'(b)$. There are also two cases: (1) $\phi \in (1,2)$, $I'(b) > 0$; (2) $\phi \in (2,\infty)$, $I'(b)$ changes from negative to positive when b increase. Now we can judge the sign of $I(b)$ according to the information we discussed above.

In the case $\phi \in (1,2)$, $I(b)$ is increasing in b and $[I(b)]_{\max} = I(1) = -25\phi < 0$. So $I(b) < 0$. In the case $\phi \in (2,\infty)$, $I(b)$ is decreasing in b first and then increasing in b. We compute $I(1) = -25\phi < 0$, so only when $I(0) = 64(-4+\phi)\phi > 0$ would there be a positive value of $I(b)$. That is to say when $\phi \in (4,\infty)$, $b \in (0, b_6)$, $I(b) > 0$ where b_6 satisfied $256\phi - 64\phi^2 - (256\phi - 128\phi^2)b_6 - (96\phi + 64\phi^2){b_6}^2 + 128\phi {b_6}^3 - (4-20\phi){b_6}^4 + (8 - 36\phi){b_6}^5 - (4-9\phi){b_6}^6 = 0$.