Online Marketplaces' Choice of Delivery Fees and Fulfillment Center Locations*

Hiroshi AIURA †
Toshiki KODERA ‡

Abstract

Online marketplaces provide an opportunity for producers to sell their products to consumers and deliver the goods from their fulfillment centers. This study analyzes the choice of fulfillment center locations and delivery fees by online marketplaces. To do this, we propose a spatial model in which online marketplaces choose fulfillment center locations and charge discriminatory or uniform delivery fees according to various market situations. We find that a location-price equilibrium depends on the unit delivery cost. This implies that if the unit delivery cost is sufficiently low, the online marketplace offers consumers free delivery and chooses a location at the center of the market area.

Keywords : price discrimination, location choice, spatial competition, free shipping, online marketplace

JEL classification : L11, L81

1　Introduction

Online marketplaces generate revenue by providing opportunities for small producers to sell their products. Additionally, some recent marketplaces (e.g., Amazon and JD) provide fulfillment services, including the delivery of the sold

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† Faculty of Economics, Nanzan University. E-mail: aiura@nanzan-u.ac.jp

‡ School of Economics, Meisei University. E-mail: toshiki.kodera@meisei-u.ac.jp

goods.[1] They set up fulfillment centers to handle large transaction volumes, from which many sold goods have been delivered. Considering that online marketplaces can shift delivery costs to the consumers by charging delivery fees, strategies regarding fulfillment center locations and delivery fees are important for online marketplaces that provide fulfillment services. For example, Zalando, a German online fashion retailer operating in 17 European markets, has fulfillment centers in various countries to save delivery time and cost. Zalando implemented differential delivery fees in these countries. For instance, when an order is below €24.90, Zalando charges €3.50 for delivery in Italy, whereas in France and Belgium, they offer free shipping.[2] As such, we investigate a location-price game in which online marketplaces can charge subscription fees for producers and delivery fees for consumers. The model allows online marketplaces to discriminate delivery fees, as delivery costs differ by location. We show that the consumers' preferences for online marketplaces affect location patterns, delivery fees, and subscription fees.

Meanwhile, there are online marketplaces that charge a uniform delivery fee and those that offer free delivery to the consumers. For instance, Amazon offers free delivery services to the consumers living in Germany, Belgium, Austria, and so on, who buy books with standard delivery. However, we apply our model to cases where online marketplaces charge consumers a uniform delivery fee. Moreover, we investigate the most desirable price policy online marketplaces between discriminatory delivery fees and a uniform delivery fee.

Spatial price discrimination and location choice have been studied by Lederer and Hurter (1986), Anderson and De Palma (1988), Konrad (2000), Dorta-González et al. (2005), Matsumura and Matsushima (2005), Heywood and Ye (2009), Colombo (2011), and Reggiani (2014). Lederer and Hurter (1986) show the existence of an equilibrium state that minimizes social cost. Reggiani (2014) examines the spokes model for the interaction between market segments and the number of firms in the market. The author shows that the equilibrium location pattern minimizes social

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1 Some recent empirical studies focus on the relationship between demand and delivery services on e-commerce. Houde et al. (2017) examine Amazon's decision of fulfillment center locations with regard to revenue and savings on shipping costs. De Castro (2019) estimates the impact of delivery speed on welfare.

2 See Guinebault, M., 2019, *H&M, Asos, Zalando introduce policies to reduce impact of delivery costs,* viewed 11 Aug. 2022, <https://ww.fashionnetwork.com/news/H-m-asos-zalando-introduce-policies-to-reduce-impact-ofdelivery-costs,1092454.html>

cost when the number of segments is larger than the number of firms.

Previous studies on uniform delivered pricing in oligopoly showed that there is no equilibrium in pure strategies (Schuler and Hobbs, 1982; Beckmann and Thisse, 1986). Nevertheless, this nonexistence problem has been overcome by several papers.[3] Assuming the heterogeneity of products or consumers' heterogeneous tastes for the products, de Palma et al. (1987) and Anderson et al. (1992) show that equilibrium does exist.

These preceding studies simplify the provision of goods or assume that firms provide the goods themselves. However, online marketplaces do not manufacture many of the goods they offer; they generally mediate transactions and charge not only the consumers but also producers, for their services. We construct the model based on Lederer and Hurter (1986) and Beckmann and Thisse (1986), in which online marketplaces provide homogeneous fulfillment services. We show that the existence of revenue from producers changes the equilibrium locations when the equilibrium delivery fees are zero within a certain segment of a linear space.

It is well known that firms might provide their products without charge when the business has privacy and data security, two-sided market, switching costs, or complementary goods (OECD, 2018). The studies dealing with these business structures in the spatial competition model include Gabszewicz et al. (2002), Gehrig and Stenbacka (2004), Lambertini and Orsini (2013), Rasch and Wenzel (2013), Behringer and Filistrucchi (2015), and so on. Although these previous studies are similar to the present one, they differ in terms of determining who, between firms and consumers, incurs the so-called transportation costs resulting from the spatial difference in the locations of a firm and a consumer. These previous studies consider product differentiation and assume that consumers incur the transportation costs interpreted as disutility, whereas the present study considers geographical differentiation and assumes that firms incur transportation costs and can charge different delivery fees at different locations.

Our spatial price discrimination model relates to the literature on vertical supply chain. Gupta et al. (1997) study a vertical relationship in which downstream firms choose their locations and delivered prices. They show that the locations of downstream firms affect the wholesale price charged by the upstream monopolist.

3 The equilibrium in mixed strategies is studied by Zhang and Sexton (2001). Another approach is to research an equilibrium in an infinitely repeated game (Espinosa, 1992).

Matsumura (2003) shows that exclusive territories imposed by an upstream monopolist stimulate competition between downstream firms in the shipping model. Heywood et al. (2018) investigate the effect of resale price maintenance with spatial price discrimination. They show that resale price maintenance enhances consumer surplus and social welfare when the transportation cost is relatively small. We, however, adopt a different approach. In our model, marketplaces do not decide retail prices. Rather, upstream producers may set the retail prices; however, they need to pay a subscription fee to sell their goods through the online marketplaces.

The remainder of this paper is structured as follows. First, Section 2 sets up a model of spatial price discrimination and location choice for online marketplaces based on Lederer and Hurter (1986), then derives the equilibrium and compares it to that of Lederer and Hurter (1986). In Section 3, we study the uniform delivery fee and location choice of online marketplaces. Moreover, we compare the profits of two online marketplaces under two pricing policies. Finally, Section 4 concludes the paper.

2 Method

2.1 Model

There are two online marketplaces (hereafter, called marketplaces) that enable consumers and small producers to interact. In this model, we assume that the marketplaces provide goods delivery services to the consumers instead of producers; thus, the charger of delivery fees changes from the producers to marketplaces. Producers' goods are stored in the fulfillment centers of the marketplaces and the sold goods are delivered from these centers to the consumers. Therefore, in the model, we analyze the location choice for the fulfillment centers and the price setting for the delivery services.

We assume that marketplace i ($i = 1, 2$) builds one fulfillment center and chooses its location, l_i, on a consumer market represented by a line of unit length. If marketplace i located at l_i delivers the goods to the consumer located at x, the delivery cost is written as $t\,|x - l_i|$, where $t > 0$ is the unit delivery cost. We assume that the other costs of the marketplaces are fixed and sunk, and thus, equal to zero, without loss of generality. Therefore, marketplace i charges delivery fees to consumers and subscription fees to producers as compensation for the delivery services. These delivery fees differ by location and are denoted by $p_i(x)$, where x

denotes the consumer's location. The subscription fees are denoted by r_i. Therefore, the profit of marketplace i is given by

$$\Pi_i \equiv |A_i|\, r_i + \int_{x \in B_i} \left[p_i(x) - t\,|x - l_i|\right] dx,$$

where A_i and $|A_i|$ denote the set and number of producers joining marketplace i, respectively, and B_i denotes the segment in which consumers join marketplace i.

The consumers, being uniformly distributed in the market, buy a set of goods from the marketplaces. We assume that each consumer has a unit demand for the goods of each producer in the marketplace that he/she chooses. The benefit of buying a set of goods from the marketplaces i is given by, $v(A_i) \equiv \bar{v} + \int_{k \in A_i} w(k)dk$, where the first term of $v(A_i)$ denotes the benefits of using marketplace i, while the second term $v(A_i)$ denotes the benefits of buying a set of goods equal to the sum of the customer's willingness to pay. We assume that $\bar{v}$ is large enough to choose either of the marketplaces.

If the consumer is located at x buys through marketplace i located at l_i, he/she not only pays the price of the goods to the producer, $c(k)$ $(k \in A_i)$, through marketplace i, but also pays a delivery fee, $p_i(x)$, to marketplace i. Accordingly, the utility of the consumer located at x in choosing marketplace i is given by,

$$U_i(x) \equiv \bar{v} - p_i(x) + \int_{k \in A_i} (w(k) - c(k))dk, \tag{1}$$

thus, the consumers choose the marketplace giving them a higher utility.

Typically, there are many small producers in markets. Here, the number of producers is normalized to 1. The producers sell goods not substitutable with others (that is, each producer acts as a monopolist). Moreover, the producers in the marketplace can track online consumer behavior perfectly and sell their products at the discriminated price equal to each consumer's willingness to pay, that is, $c(k) = w(k)$ for any k.[4] Substituting $c(k) = w(k)$ into Eq. (1), we obtain

$$U_i(x) \equiv \bar{v} - p_i(x). \tag{2}$$

4 This assumption relates to behavior-based price discrimination, in which firms offer different prices to consumers based on the consumers' purchase histories (see overview in Fudenberg and Villas-Boas (2006)). Bikhchandani and McCardle (2012) show that a patient firm with consumers' purchase histories can set higher prices for consumers that purchased previously.

The average price for the goods each producer sells is uniformly distributed in [0, 1]. The producers produce goods at constant marginal costs and we assume that these marginal costs are equal to zero, without loss of generality. Therefore, the profit from selling the goods whose average price is θ through marketplace i is given by $\pi_i(\theta) \equiv \theta\,|B_i| - r_i$, where θ denotes the average price and $|B_i|$ denotes the number of consumers joining marketplace i. If $\pi_i(\theta) \geq 0$, the producers would choose to sell their products through marketplace i.

The timing of the game is as follows:

1. Marketplace i chooses the location of its own fulfillment center, $l_i \in [0, 1]$, $l_1 \leq 1/2 \leq l_2$, on the market.
2. Given location l_i, the marketplace determines the delivery fee, $p_i(x) \geq 0$, for the consumer located at x and the subscription fees, r_i, for the producers. The consumers then choose a marketplace to buy a set of goods, while the producers decide to join one, both, or neither marketplace. The producers' goods are sold to the consumers who join the same marketplace and the profits of the marketplaces are determined.

As shown above, the marketplaces decide the location, delivery fees, and subscription fees through the game to maximize their profits at the final stage. In the next section, we solve the game through backward induction and find a subgame perfect equilibrium.

2.2 Equilibrium

In stage 2, the producers can sell their goods to consumers who join the same marketplace. A producer does not earn a positive profit through marketplace i if his/her price is lower than $\hat{\theta}_i = r_i / |B_i|$. Thus, the number of producers joining marketplace i is $|A_i| = 1 - \hat{\theta}_i = 1 - r_i / |B_i|$.

Since the subscription fees, r_i, influence the number of producers but not the number of consumers joining marketplace i, the marketplace can set the subscription fee to maximize the total subscription fees obtained from the producers joining it, which is equal to $|A_i|\, r_i = (1 - r_i / |B_i|)\, r_i$. The following lemma characterizes the revenue from the producers.

Lemma 1 *Given the locations and delivery fees, the subscription fee is maximized at $\hat{r}_i\,(p_i\,(x)\,,\,l_i) = |B_i|\,/2$. The number of producers who subscribe to marketplace i is $|A_i| = 1/2$. Therefore, marketplace i's revenue from the producers is $|B_i|\,/4$.*

Lemma 1 implies that the equilibrium number of producers is a constant and the equilibrium subscription fee for the producers depends on the number of consumers who join the same marketplace. The number of consumers who join marketplace i becomes larger, and marketplace i's revenue from the producers increases because the marketplace can set a higher subscription fee.

Marketplace i chooses a delivery fee $p_i(x)$ for the location of its fulfillment center. A consumer located at x purchases a set of goods from the marketplace that sets the lowest delivery fee (as shown in Eq. (2)). If the delivery fee is the same between the marketplaces, we adopt a cost advantage sharing rule, as defined by Lederer and Hurter (1986), whereby a consumer chooses the marketplace with the least total marginal costs.[5]

The marginal revenue of marketplace i to gain an additional consumer located at x can be written as

$$p_i(x) + \frac{d\left(|A_i|\, r_i\right)}{d\,|B_i|} = p_i(x) + \frac{1}{4}. \tag{3}$$

Note that the marginal revenue is equal to the revenue from the consumers and producers because an increase in the number of consumers raises the subscription fee, as shown in Lemma 1.

Marketplace i sets its delivery fee to be slightly cheaper than that of the other marketplace to gain an additional consumer as long as the delivery fee exceeds 0 and its marginal revenue is above its marginal delivery cost (that is, $p_i(x) > 0$ and $p_i(x) + 1/4 > t\,|x - l_i|$). Therefore, the equilibrium delivery fee is confirmed by the following proposition:

Proposition 1 *Given the locations, the equilibrium delivery fee for marketplace i is*

$$p_i^*(x) = \max\left\{t\,|x - l_i| - \frac{1}{4},\ t\,|x - l_j| - \frac{1}{4},\ 0\right\},$$

and the equilibrium subscription fee for marketplace i is $r_i^* = \hat{r}_i\left(p_i^*(x), l_i\right)$.

In stage 1, marketplace i chooses a location for its fulfillment center, l_i. Under

5 A cost-advantage-sharing rule is justified because a cost advantages marketplace can afford to cut its delivery fees, compared to other marketplaces.

equilibrium, the marketplaces choose the same delivery fee for any location. Given the equilibrium delivery fee and cost-advantage-sharing rule, the profit of marketplace i is given by

$$\begin{aligned}\Pi_i &= \int_{\{x\in[0,1]|t|x-l_i|<t|x-l_j|\}} [p_i^*(x) - t\,|x-l_i|]\,dx + \frac{|B_i|}{4} \\ &= \int_{\{x\in[0,1]|t|x-l_i|<t|x-l_j|\}} \left[p_i^*(x) - t\,|x-l_i| + \frac{1}{4}\right] dx.\end{aligned} \tag{4}$$

The first and second terms on the right-hand side in Eq. (4) denote the profit from the delivery to the consumers and the revenue from the producers, respectively.

The equilibrium delivery fee is minimized, at least at the location $(l_1+l_2)/2$.[6] Therefore, if $t\,|l_2-l_1| > 1/2$, marketplace i offers a positive delivery fee for all the consumers and its profit can be rewritten as

$$\Pi_i = \int_{\{x\in[0,1]|t|x-l_i|<t|x-l_j|\}} [t\,|x-l_j| - t\,|x-l_i|]\,dx. \tag{5}$$

This profit function comprises two transportation costs borne by both marketplaces to deliver the goods to the consumer located at x, and only considers the consumer side to determine his location, which is consistent with Lederer and Hurter (1986).

If $t\,|l_2-l_1| \leq 1/2$, the marketplaces do not offer a delivery fee for the consumers in a certain segment. The profit of marketplace i is then rewritten as

$$\begin{aligned}\Pi_i = &\int_{\{x\in[0,1]|t|x-l_i|<t|x-l_j| \text{ and } p_i^*(x)>0\}} [t\,|x-l_j| - t\,|x-l_i|]\,dx \\ &+ \int_{\{x\in[0,1]|t|x-l_i|<t|x-l_j| \text{ and } p_i^*(x)=0\}} \left[\frac{1}{4} - t\,|x-l_i|\right] dx,\end{aligned} \tag{6}$$

which implies that the marketplaces obtain a positive profit even if they do not charge the consumers delivery fees because they obtain a positive profit from the producers. At a symmetric equilibrium; that is, $l_1 = 1 - l_2$, we state the following proposition.

6 This location is derived by solving $t\,|x-l_1| - 1/4 = t\,|x-l_2| - 1/4$ for x.

Proposition 2 *The equilibrium location patterns and delivery fees of marketplace i are*

$$\text{(i) if } t > 1, (l_1^*, l_2^*) = \left(\frac{1}{4}, \frac{3}{4}\right),$$

$$p_i^*(x) = \begin{cases} t(l_2^* - x) - \frac{1}{4} & \text{for } x \in \left[0, \frac{1}{2}\right] \\ t(x - l_1^*) - \frac{1}{4} & \text{for } x \in \left[\frac{1}{2}, 1\right] \end{cases},$$

$$\text{(ii) if } 1 \geq t > \frac{2}{5}, (l_1^*, l_2^*) = \left(\frac{2t+1}{12t}, \frac{10t-1}{12t}\right),$$

$$p_i^*(x) = \begin{cases} t(l_2^* - x) - \frac{1}{4} & \text{for } x \in \left[0, \frac{5t-2}{6t}\right] \\ 0 & \text{for } x \in \left[\frac{5t-2}{6t}, \frac{t+2}{6t}\right] \\ t(x - l_1^*) - \frac{1}{4} & \text{for } x \in \left[\frac{t+2}{6t}, 1\right] \end{cases},$$

$$\text{(iii) if } \frac{2}{5} \geq t > \frac{1}{4}, (l_1^*, l_2^*) = \left(\frac{2t+1}{12t}, \frac{10t-1}{12t}\right), \ p_i^*(x) = 0,$$

$$\text{(iv) if } \frac{1}{4} \geq t, (l_1^*, l_2^*) = \left(\frac{1}{2}, \frac{1}{2}\right), \ p_i^*(x) = 0.$$

The equilibrium location patterns depend on t. By differentiating the equilibrium locations of (ii) and (iii), we obtain

$$\frac{dl_1^*}{dt} = -\frac{1}{12t^2} < 0, \ \frac{dl_2^*}{dt} = \frac{1}{12t^2} > 0.$$

As the unit delivery cost t decreases, the marketplaces tend to choose locations that are more similar. In results (i) and (ii), the delivery fees also depend on t. As t decreases, the marketplaces expand the interval over which they offer free delivery fees in (ii).

If $t > 1$, the outcome in result (i) is identical to the outcome of Lederer and Hurter (1986) and its implication is consistent with that of their model, specifically, a marketplace chooses its location to relax price competition and minimize its transportation cost.

In results (ii) and (iii), the marketplaces choose intermediate locations; that is, $1/4 \leq l_1^* = (2t+1)/12t < 1/2 < l_2^* = (10t-1)/12t \leq 3/4$. The intuition is as follows: If $1 \geq t$, the marketplaces face a tradeoff when choosing their location minimizing their transportation cost and maximizing revenue from the producers. As t decreases, the consumers not charged delivery fees increase because of the intensified competition in delivery fees between the marketplaces. In this case, the marketplaces give up their delivery fee revenue. As such, the marketplaces move toward the center in order to increase revenue from the producers by increasing the number of the consumers joining their marketplaces. Accordingly, the marketplaces are located between one-quarter (or three-quarter) and the center of the market area; finally, they are located at the center if $1/4 \geq t$.

3 Discussion

3.1 Uniform delivery fee

In this subsection, marketplace i offers a single delivery fee to all the consumers located in the area where the marketplace can provide a delivery service. Since the marginal revenue of marketplace i is given by Eq. (3), the marketplace sets a uniform delivery fee, p_i^U, to cover the transportation cost from the marketplace and the marginal revenue from the producers; that is, $p_i^U \geq \max\{t\,|x - l_i| - 1/4,\, 0\}$. Since the marketplaces supply a homogeneous service, the consumers purchase the producers' goods sold by the marketplace offering a lower delivery fee. Assuming that marketplace j charges $\tilde{p}_j^U$ to deliver goods to all the consumers, the segment of consumers served by marketplace i is given by

$$\begin{aligned} B_i &= \left[l_i - \min\left\{\tfrac{4p_i^U+1}{4t},\, l_i\right\},\, l_i + \min\left\{\tfrac{4p_i^U+1}{4t},\, 1 - l_i\right\}\right] && \text{if } p_i^U < \tilde{p}_j^U, \\ &= \left[0,\, \tfrac{l_1+l_2}{2}\right] && \text{if } p_i^U = \tilde{p}_j^U, \\ &= \emptyset && \text{if } p_i^U > \tilde{p}_j^U. \end{aligned}$$

If $p_i^U < \tilde{p}_j^U$, marketplace i serves all or a part of the consumers, the rest are served by marketplace j. If $p_i^U = \tilde{p}_j^U$, marketplace i may deliver to all the consumers, and the consumers will buy the goods from the nearest marketplace. If $p_i^U > \tilde{p}_j^U$, all the consumers will buy from marketplace j. As in Eq. (4), the profit of marketplace i is as follows:

$$\Pi_i = \int_{B_i} \left[p_i^U - t\,|x - l_i| + \frac{1}{4}\right] dx.$$

Thus, at a symmetric equilibrium, we have the following proposition.

Proposition 3 *The equilibrium location patterns and uniform delivery fees of marketplace i are*

$$\begin{array}{lll}
\text{(i) if } \tilde{t} \geq t > \frac{1}{4}, & (l_1^*, l_2^*) = \left(\frac{2t+1}{12t}, \frac{10t-1}{12t}\right), & p_i^{U*} = 0, \\
\text{(ii) if } \frac{1}{4} \geq t, & (l_1^*, l_2^*) = \left(\frac{1}{2}, \frac{1}{2}\right), & p_i^{U*} = 0,
\end{array}$$

where

$$\tilde{t} = \frac{2 + 5\varepsilon - \sqrt{12\varepsilon + 25\varepsilon^2}}{2},$$

with a sufficiently small $\varepsilon > 0$. *Furthermore, there exists no equilibrium if and only if* $t > \tilde{t}$.

In the location-price equilibrium, delivery is free for all the consumers. For $t \leq \tilde{t}$, since the marketplaces can costlessly deliver to the consumers, the marketplaces compete fiercely for consumers. Therefore, by leveraging the revenue from the producers, the marketplaces offer free shipping to the consumers who live in the market area. Furthermore, in cases (ii), (iii), and (iv) of Proposition 2, the equilibrium location patterns also depend on the unit delivery cost. In contrast, if $t > \tilde{t}$, there exists no price equilibrium, which is the same result described by Schuler and Hobbs (1982) and Beckmann and Thisse (1986).

3.2 Comparison between discriminatory pricing and uniform pricing

In this subsection, we compare the results given discriminatory delivery fees and uniform delivery fees. Welfare is the sum of the marketplace's profits, consumer surplus, and producer surplus. Since all the consumers participate in the marketplaces at equilibrium, and the equilibrium location patterns are the same under both pricing schemes, welfare and producer surplus are the same under the two pricing schemes. Accordingly, the sum of the marketplace's profits and consumer surplus under discriminatory pricing is identical to that under uniform pricing. This suggests that a decrease in the marketplace's profits reflects an increase in consumer surplus.

We consider the marketplace's profits under both pricing schemes. As stated in Propositions 2 and 3, the profits of the marketplace depend on t (see Figure 1). Because ε is small enough, $2/5 < \tilde{t} < 1$. For $t \leq 2/5$, the equilibrium results under price discrimination are equal to those under uniform pricing. Therefore, the marketplace's profits are the same under both pricing schemes. There are two types of cost-saving effects in the marketplace's profit. The first effect, which is

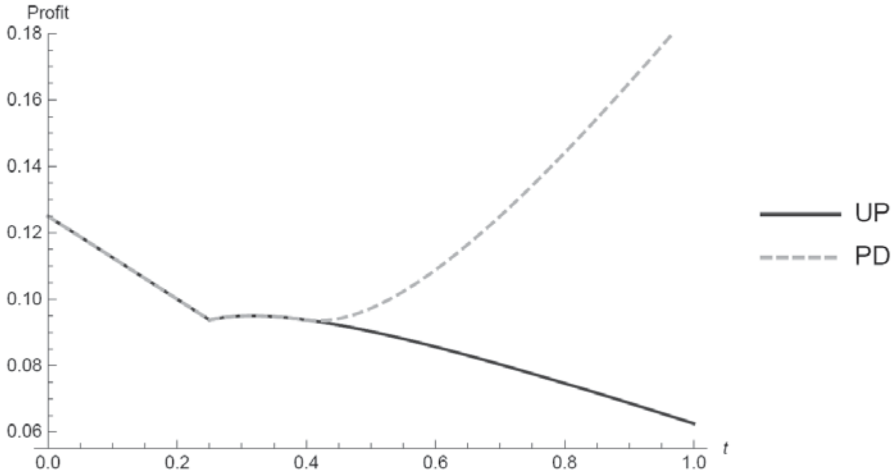

Figure 1　Profit under price discrimination and uniform pricing

the direct effect, increases profits by directly reducing the unit delivery cost t. The second effect, which we call the location adjustment effect, dictates that as t rises, the marketplaces adjust their location to suppress delivery costs by shortening their distance from the consumers. For $t \leq 1/4$, since only the first effect is active, the marketplace's profits decrease with the unit delivery cost. For $1/4 < t \leq 2/5$, both effects are active, and the marketplace's profit functions are hump-shaped in the unit delivery cost. Since the second effect is stronger than the first effect for $1/4 < t < 1/\sqrt{10}$, the marketplace's profits increase with the unit delivery cost.

For $2/5 < t \leq \tilde{t}$, the same equilibrium location patterns are chosen under both pricing schemes; in contrast, the equilibrium prices are different. Under uniform pricing, the marketplaces offer free delivery to all the consumers, as opposed to positive delivery fees to some consumers under price discrimination. Consequently, the marketplace's profit under price discrimination is higher than that under uniform pricing for $2/5 < t \leq \tilde{t}$. Under price discrimination, the marketplace's profit increases with the unit delivery cost. Then, there is the third effect, which dictates that as t rises, the marketplace increases its market power for the consumers located far from the competitor. This effect, which we call the market power effect, and the location adjustment effect outweigh the direct effect. Under uniform pricing, as t rises, the marketplace's profit decreases. Since the marketplace offers free delivery, the direct effect and the location adjustment effect are active. In this case, the direct effect outweighs the location adjustment effect.

Consumer surplus, which is given as a function of t, is the opposite of the marketplace's profits. For $t \leq 2/5$, consumer surplus under both pricing schemes is the same. In contrast, for $2/5 < t \leq \tilde{t}$, the consumer surplus under uniform pricing is higher than that under price discrimination.

3.3 Price discrimination with quadratic transportation cost

In this sub-section, we consider quadratic transportation costs in determining the equilibrium location pattern and delivery fee. First, we consider that quadratic transportation costs do not have an effect on the revenue from the producers in equilibrium. Therefore, the marketplaces set subscription fees for the producers following Lemma 1. Given the locations, the delivery fee is

$$p_i^*(x) = \max\left\{t\left(x - l_i\right)^2 - \frac{1}{4},\, t\left(x - l_j\right)^2 - \frac{1}{4},\, 0\right\}.$$

Following Proposition 2, we can derive the symmetric equilibrium location patterns and delivery fees. We relegate the proof to the Appendix.

Proposition 4 *The equilibrium location patterns and delivery fees of marketplace i are*

(i) if $t \geq 4$, $(l_1^*, l_2^*) = \left(\frac{1}{4}, \frac{3}{4}\right)$,

$$p_i^*\left(x\right) = \begin{cases} t\left(x - l_2^*\right)^2 - \frac{1}{4} & \text{for } x \in \left[0,\, \frac{1}{2}\right] \\ t\left(x - l_1^*\right)^2 - \frac{1}{4} & \text{for } x \in \left[\frac{1}{2},\, 1\right] \end{cases},$$

(ii) if $4 > t > \frac{36}{49}$, $(l_1^*, l_2^*) = \left(\frac{-t + \sqrt{t + 2t^2}}{2t}, \frac{3t - \sqrt{t + 2t^2}}{2t}\right)$,

$$p_i^*\left(x\right) = \begin{cases} t\left(x - l_2^*\right)^2 - \frac{1}{4} & \text{for } x \in \left[0,\, \frac{3t - \sqrt{t}\left(1 + \sqrt{2t+1}\right)}{2t}\right] \\ 0 & \text{for } x \in \left[\frac{3t - \sqrt{t}\left(1 + \sqrt{2t+1}\right)}{2t},\, \frac{-t + \sqrt{t}\left(1 + \sqrt{2t+1}\right)}{2t}\right] \\ t\left(x - l_1^*\right)^2 - \frac{1}{4} & \text{for } x \in \left[\frac{-t + \sqrt{t}\left(1 + \sqrt{2t+1}\right)}{2t},\, 1\right] \end{cases},$$

(iii) if $\frac{36}{49} \geq t > \frac{1}{2}$, $(l_1^*, l_2^*) = \left(\frac{-t + \sqrt{t + 2t^2}}{2t}, \frac{3t - \sqrt{t + 2t^2}}{2t}\right)$, $p_i^*\left(x\right) = 0$,

(iv) if $\frac{1}{2} \geq t$, $(l_1^*, l_2^*) = \left(\frac{1}{2}, \frac{1}{2}\right)$, $p_i^*\left(x\right) = 0$.

The quadratic transportation costs maintain the property of consequence. The intuition behind the equilibrium is similar to that of Proposition 2. If t is sufficiently high, the marketplaces choose their locations to minimize the social transportation cost. As t decreases, the marketplace moves toward the center.

4 Conclusions

This study investigates the locations of fulfillment centers and delivery fees (discriminatory and uniform delivery fees) strategies that online marketplaces apply. We find that the equilibrium outcomes depend on the transportation cost. In the discriminated delivery fee model, if the transportation cost is sufficiently large, the marketplace sets a positive delivery fee for all the consumers and locates the fulfillment center at one-quarter and three-quarters of the market area. If the transportation cost is sufficiently small, the marketplace does not charge delivery fees and locates the fulfillment center at the center of the market. The latter result has not been shown in previous studies on spatial price discrimination and location choice. Under the uniform delivery fee scheme, if the transportation cost is small, marketplaces provide free delivery. In such cases, a location-price equilibrium exists. For discriminatory pricing and uniform pricing, the equilibrium locations are the same. If transportation costs are moderate, the two pricing policies lead to different marketplace profits. Under the uniform delivery fee scheme, the marketplace's profit decreases with the transportation costs. In contrast, under discriminatory pricing, the marketplace's profit increases with the transportation costs.

This analysis has some limitations that should be addressed in future research. First, in our model, the marketplaces do not charge transaction fees to the producers. Second, the consumers may experience the network effects resulting from the producers using the same marketplace. We will tackle these questions in future research.

Appendix

Proof of Proposition 1.

Suppose that the marketplaces choose the equilibrium delivery fee $p^*(x) = p_i^*(x) = p_j^*(x)$, where $p^*(x) = \max\left\{t\,|x-l_i| - \frac{1}{4},\, t\,|x-l_j| - \frac{1}{4},\, 0\right\} + \delta$ for $\delta > 0$. In this scenario, marketplace j changes its delivery fee to $p_j'(x) = p^*(x) - \varepsilon \geq 0$, where ε is sufficiently small and positive, for the consumers who choose marketplace i. Subsequently, marketplace j increases its profit. Here, $p^*(x)$ is in contradiction to the equilibrium delivery fee.

Suppose still that the marketplaces choose the equilibrium delivery fee $p^*(x)=p_i^*(x)=p_j^*(x)$, where $p^*(x)=\max\left\{t|x-l_i|-\frac{1}{4},\ t|x-l_j|-\frac{1}{4}\right\}-\delta\geq 0$ for $\delta>0$. Again marketplace j changes its delivery fee to $p_j'(x)=p^*(x)+\varepsilon\geq 0$, where ε is sufficiently small and positive. The profits of marketplace j increase here too. $p^*(x)$ is, again, in contradiction to the equilibrium delivery fee.

Now, since the delivery fee does not depend on the subscription fee, we can derive the equilibrium subscription fee by Lemma 1.

Proof of Proposition 2.

We derive the equilibrium location patterns and delivery fees for the four cases.

(i) $t(l_2-l_1)/2>1/4$

In this case, marketplace i sets positive delivery fees for the consumers located at $(l_1+l_2)/2$. Then, the marketplaces may charge positive delivery fees for all the consumers. The profit of marketplace i is

$$\Pi_i=\int_{\{x\in[0,1]\mid t|x-l_i|<t|x-l_j|\}}[t|x-l_j|-t|x-l_i|]\,dx.$$

Given the location of marketplace j, marketplace i chooses a location to minimize the transportation cost. The equilibrium location pattern is $(l_1^*,\ l_2^*)=(1/4,\ 3/4)$. Substituting the equilibrium locations for $t(l_2-l_1)/2>1/4$, we derive a condition for t; that is, $t>1$.

(ii) $t(l_2-l_1)\leq 1/4$ and $l_2-1/4t>0$

Here, the marketplaces offer free shipping for the consumers in $[l_2-1/4t,\ l_1+1/4t]$ and positive delivery fees for the consumers in $[0,\ l_2-1/4t]$ and $[l_1+1/4t,\ 1]$. The profit of marketplace 1 is

$$\Pi_1=\int_0^{l_2-\frac{1}{4t}}\left[t(l_2-x)-\frac{1}{4}\right]dx-\int_0^{l_1}t(l_1-x)\,dx-\int_{l_1}^{\frac{l_1+l_2}{2}}t(x-l_1)\,dx+\frac{l_1+l_2}{8}.$$

The first-order condition of profit maximization is

$$\frac{\partial\Pi_1}{\partial l_1}=\frac{t(2l_2-10l_1)+1}{8}=0. \tag{7}$$

Solving the first-order conditions, we derive the equilibrium location pattern,

$$(l_1^*, l_2^*) = \left(\frac{2t+1}{12t}, \frac{10t-1}{12t} \right). \tag{8}$$

Substituting the equilibrium locations for $l_2 - 1/4t$ and $l_1 + 1/4t$, we derive the interval at which the marketplaces offer free shipping; that is, $[(5t-2)/6t, (t+2)/6t]$. Then, the condition of t is $1 \geq t > 2/5$.

(iii) $l_2 > l_1$ and $l_2 - 1/4t \leq 0$

Here, the marketplaces offer free shipping for all the consumers. Then, the profit of marketplace 1 is

$$\Pi_1 = -\int_0^{l_1} t(l_1 - x)\,dx - \int_{l_1}^{\frac{l_1+l_2}{2}} t(x - l_1)\,dx + \frac{l_1 + l_2}{8}. \tag{9}$$

The first-order condition of profit maximization is equal to Eq. (7). Consequently, by solving the first-order conditions, the equilibrium location pattern is Eq. (8). If $t = 1/4$, the equilibrium locations are $l_1^* = l_2^* = 1/2$. Substituting the equilibrium locations for $l_2 > l_1$, the condition for t is $2/5 \geq t > 1/4$.

(iv) If $t < 1/4$, $\partial \Pi_1 / \partial l_1 > 0$ and $\partial \Pi_2 / \partial l_2 < 0$. Then, the equilibrium locations are $l_1^* = l_2^* = 1/2$.

Proof of Proposition 3.

Suppose that there exists an equilibrium given by $\left(p_1^{U*}, p_2^{U*}, l_1^*, l_2^*\right)$. Then, in the price-setting stage, a pair $\left(p_1^{U*}, p_2^{U*}\right)$ is a price equilibrium given the location pattern (l_1^*, l_2^*). First, let $p_1^{U*} = p_2^{U*} = p^{U*} > 0$. As with Proposition 5 of Beckmann and Thisse (1986), we show that $p_i^{U*} > 0$ is not the equilibrium price given the location pattern. If $l_1 \neq l_2$ and $p^{U*} < t(l_2 - l_1)/2 - 1/4$, in the consumer market, the share of marketplace 1 does not overlap with that of marketplace 2. Therefore, marketplace 1 can obtain additional consumers and increase profits by setting price $p^{U*} + \varepsilon$, where ε is sufficiently small and positive. This contradicts the equilibrium condition. If $l_1 \neq l_2$ and $p^{U*} > t(l_2 - l_1)/2 - 1/4$, the consumer's market separates at $(l_1 + l_2)/2$. Marginal consumers served by marketplace 1 stay $(l_2 - l_1)/2$ away from marketplace 1. Then, the number of consumers joining marketplace 1 is given by $B_1 = \min\left\{\left(p^{U*} + 1/4\right)/t, l_1\right\} + (l_2 - l_1)/2$. Since $\left(p^{U*} + 1/4\right)/t > (l_2 - l_1)/2$, if marketplace 1 charges $p^{U*} - \varepsilon \geq 0$ with sufficiently small $\varepsilon > 0$, marketplace 1 can expand the share on the consumer market by $\left(p^{U*} - \varepsilon + 1/4\right)/t$ and increase profits. This contradicts the equilibrium condition. If $l_1 \neq l_2$ and $p^{U*} = t(l_2 - l_1)/2 - 1/4$, marketplace 2 does not supply its service to the consumers beyond point $(l_1 + l_2)/2$. Therefore, by charging $p^{U*} + \varepsilon$, where ε is sufficiently small and positive, marketplace 1 can increase its profits. This contradicts the equilibrium condition. If $l_1 = l_2$, marketplace 1 can attract all the consumers and increase profits by setting price $p^{U*} - \varepsilon \geq 0$, where ε is sufficiently small and positive. This contradicts the equilibrium condition. Therefore, if the marketplaces charge a positive uniform delivery fee, the location-price equilibrium does not exist.

Next, let $p_1^{U*} = p_2^{U*} = p^{U*} = 0$, we show that the equilibrium exists for $t \leq \tilde{t}$. In this scenario, there are five cases. In the first case, if $t(l_2 - l_1)/2 - 1/4 \geq 0$, then marketplace 1 can deviate from the price equilibrium by setting a price $p_1^U = \varepsilon > 0$ with sufficiently small ε, representing a contradiction.

In the second case, we prove that if $t(l_2 - l_1)/2 - 1/4 < 0$ and $l_1 - 1/4t \geq 0$ (or $l_2 + 1/4t \leq 1$), then there exists no location-price equilibrium. In stage 1, the profit of marketplace 1 is given by

$$\begin{aligned} \Pi_1 &= \int_{l_1 - \frac{1}{4t}}^{l_1} \left[\frac{1}{4} - t(l_1 - x)\right] dx + \int_{l_1}^{\frac{l_1 + l_2}{2}} \left[\frac{1}{4} - t(x - l_1)\right] dx \\ &= \frac{1}{8}\left(l_2 - l_1 + \frac{1}{4t}\right) - \frac{t}{8}(l_2 - l_1)^2 . \end{aligned} \tag{10}$$

Differentiating the profit of marketplace 1 with respect to l_1 obtains

$$\frac{\partial \Pi_1}{\partial l_1} = \frac{1}{2}\left(\frac{t(l_2 - l_1)}{2} - \frac{1}{4}\right) < 0.$$

Similarly, differentiating the profit of marketplace 2 with respect to l_2, we have $\partial \Pi_2 / \partial l_2 > 0$. Since $l_1 \geq 1/4t$ and $l_2 \leq 3/4t$, the marketplaces choose the location pattern $(\bar{l}_1, \bar{l}_2) = (1/4t, 3/4t)$. However, given the location pattern $(\bar{l}_1, \bar{l}_2)$, the price equilibrium does not exist. In stage 2, by setting the price at $p_1^U = \varepsilon > 0$, with sufficiently small ε, marketplace 1 deviates from the equilibrium price given the location pattern $(\bar{l}_1, \bar{l}_2)$. Then, marketplace 1 provides its servicses to the consumers in $[0, 1/2t]$. The profit of marketplace 1 is as follows:

$$\begin{aligned} \Pi_{1\varepsilon} &= \int_0^{\bar{l}_1} \left[\frac{1}{4} + \varepsilon - t(\bar{l}_1 - x)\right] dx + \int_{\bar{l}_1}^{\frac{1}{2t}} \left[\frac{1}{4} + \varepsilon - t(x - \bar{l}_1)\right] dx \\ &= \frac{1}{16t} + \frac{\varepsilon}{2t}. \end{aligned}$$

Under the marketplaces located at $(\bar{l}_1, \bar{l}_2)$, since the profit of marketplace 1, shown by Eq. (10), is $\Pi_1 = 1/16t$, therefore $\Pi_{1\varepsilon} > \Pi_1$. This contradicts the equilibrium condition.

In the third case, if $t(l_2 - l_1)/2 - 1/4 < 0$, $l_1 - 1/4t < 0$ (or $l_2 + 1/4t > 1$) and $l_1 < l_2 - 1/4t$, then the location-price equilibrium exists for $5/8 < t \leq \tilde{t}$. In this case, free shipping is applied to all the consumers by both marketplaces. The profit of marketplace 1 in stage 1 is equal to Eq. (9). As with Proposition 2, by solving the first-order conditions, we have the equilibrium location pattern $(l_1^*, l_2^*) = ((2t+1)/12t, (10t-1)/12t)$. We show that if $5/8 < t \leq \tilde{t}$, then the marketplaces do not deviate from the equilibrium price given the location pattern (l_1^*, l_2^*). If marketplace 1 deviates by charging price $p_1^U = \varepsilon > 0$, where ε is sufficiently small, then the profit of marketplace 1 is as follows:

$$\begin{aligned}\Pi_{1\varepsilon} &= \int_0^{l_1^*}\left[\frac{1}{4} + \varepsilon - t(l_1^* - x)\right]dx + \int_{l_1^*}^{l_2^* - \frac{1}{4t}}\left[\frac{1}{4} + \varepsilon - t(x - l_1^*)\right]dx \\ &= -\frac{34t^2 - 68t + 25}{144t} + \frac{(5t-2)\varepsilon}{6t}.\end{aligned}$$

Given the location pattern (l_1^*, l_2^*), if marketplace 1 does not change the equilibrium price, then

$$\Pi_1 - \Pi_{1\varepsilon} = \frac{t^2 - (2+5\varepsilon)t + 1 + 2\varepsilon}{6t} \geq 0.$$

This condition holds when

$$t \leq \frac{2 + 5\varepsilon - \sqrt{12\varepsilon + 25\varepsilon^2}}{2} \equiv \tilde{t}, \quad \frac{2 + 5\varepsilon + \sqrt{12\varepsilon + 25\varepsilon^2}}{2} \leq t.$$

Since $t(l_2^* - l_1^*)/2 - 1/4 < 0$, $l_1^* - 1/4t < 0$, and $l_1^* < l_2^* - 1/4t$, we derive a condition for t; that is, $5/8 < t < 1$. Since $\tilde{t} < 1$ for sufficiently small ε, $\varepsilon > 0$, there exists a location-price equilibrium if $5/8 < t \leq \tilde{t}$.

In the fourth case, if $t(l_2 - l_1)/2 - 1/4 < 0$, $l_1 - 1/4t < 0$ (resp. $l_2 + 1/4t > 1$), and $0 < l_2 - 1/4t \leq l_1$ (resp. $l_2 \leq l_1 + 1/4t < 1$), then the location-price equilibrium exists for $2/5 < t \leq 5/8$. As in the third case, the profit of marketplace 1 in stage 1 is given by Eq. (9) and the equilibrium location pattern is $(l_1^*, l_2^*) = ((2t+1)/12t, (10t-1)/12t)$. If marketplace 1 deviates by charging price $p_1^U = \varepsilon > 0$, where ε is sufficiently small, then the profit of marketplace 1 is as follows:

$$\begin{aligned}\Pi_{1\varepsilon} &= \int_0^{l_2^*-\frac{1}{4t}}\left[\frac{1}{4}+\varepsilon-t\left(l_1^*-x\right)\right]dx\\ &= \frac{5t-2}{24}+\frac{(5t-2)\varepsilon}{6t}.\end{aligned}$$

Given the location pattern (l_1^*, l_2^*), if marketplace 1 does not change the equilibrium price, then

$$\Pi_1-\Pi_{1\varepsilon}=\frac{-40t^2+2\left(16-60\varepsilon\right)t-1+48\varepsilon}{6t}\geq 0.$$

This condition holds when

$$\underline{t}\equiv\frac{8-30\varepsilon-3\sqrt{6+100\varepsilon^2}}{20}\leq t\leq\frac{8-30\varepsilon+3\sqrt{6+100\varepsilon^2}}{20}\equiv\bar{t}.$$

Since $t\left(l_2^*-l_1^*\right)/2-1/4<0$, $l_1^*-1/4t<0$, and $0<l_2^*-1/4t\leq l_1^*$, we derive a condition for t; that is, $2/5<t\leq 5/8$. Because $\underline{t}<2/5$ and $5/8<\bar{t}$ for sufficiently small ε, $\varepsilon>0$, there exists a location-price equilibrium if $2/5<t\leq 5/8$.

In the fifth case, if $t\leq 2/5$, then each marketplace can offer free delivery to all the consumers. As in cases (iii) and (iv) of Proposition 2, if $2/5\geq t>1/4$ (resp. $1/4\geq t$), the equilibrium location pattern (l_1^*, l_2^*) is $((2t+1)/12t, (10t-1)/12t)$ (resp. $(1/2, 1/2)$).

Proof of Proposition 4.

We derive the equilibrium location patterns and delivery fees for the four cases.

(i) $t\left(l_2-l_1\right)^2>1$

In this case, marketplace i sets positive delivery fees for a consumer located at $\left(l_1+l_2\right)/2$. Then, the marketplaces can charge positive delivery fees for all the consumers. The profit of marketplace i is then given by

$$\Pi_i=\int_{\{x\in[0,1]|t(x-l_i)^2<t(x-l_j)^2\}}\left[t\left(x-l_j\right)^2-t\left(x-l_i\right)^2\right]dx.$$

Given the location of marketplace j, marketplace i chooses the location to minimize its transportation costs. The equilibrium location pattern is $(l_1^*, l_2^*)=(1/4, 3/4)$. Substituting the equilibrium locations for $t\left(l_2-l_1\right)^2>1$, we derive a condition for t; that is, $t>4$.

(ii) $t\left(l_2-l_1\right)^2 \leq 1$ and $l_2-\sqrt{t}/2t>0$

Here, the marketplaces offer free shipping for the consumers in $\left[l_2-\sqrt{t}/2t,\, l_1+\sqrt{t}/2t\right]$ and positive delivery fees for the consumers in $\left[0,\, l_2-\sqrt{t}/2t\right]$ and $\left[l_1+\sqrt{t}/2t,\, 1\right]$. Then, the profit of marketplace 1 is

$$\Pi_1=\int_0^{l_2-\frac{\sqrt{t}}{2t}}\left[t\left(l_2-x\right)^2-\frac{1}{4}\right]dx-\int_0^{\frac{l_1+l_2}{2}} t\left(x-l_1\right)^2 dx+\frac{l_1+l_2}{8}.$$

The first-order condition of profit maximization is

$$\frac{\partial \Pi_1}{\partial l_1}=\frac{t\left(l_2^2-2l_1l_2-7l_1^2\right)+1}{8}=0. \tag{11}$$

By solving the first-order conditions, we derive the equilibrium location pattern

$$\left(l_1^*,\, l_2^*\right)=\left(\frac{-t+\sqrt{t+2t^2}}{2t},\, \frac{3t-\sqrt{t+2t^2}}{2t}\right). \tag{12}$$

In substituting the equilibrium locations for $l_2-\sqrt{t}/2t$ and $l_1+\sqrt{t}/2t$, we derive the interval at which the marketplaces offer free shipping; that is, $\left[\left\{3t-\sqrt{t}\left(1+\sqrt{2t+1}\right)\right\}/2t,\, \left\{-t+\sqrt{t}\left(1+\sqrt{2t+1}\right)\right\}/2t\right]$. Then, the condition of t is $4 \geq t>36/49$.

(iii) $l_2>l_1$ and $l_2-\sqrt{t}/2t \leq 0$

Here, the marketplaces offer free shipping for all the consumers. The profit of marketplace 1 is

$$\Pi_1=-\int_0^{\frac{l_1+l_2}{2}} t\left(x-l_1\right)^2 dx+\frac{l_1+l_2}{8}.$$

We have the same first-order condition as Eq. (11). By solving the first-order conditions, we derive the same equilibrium location pattern as in Eq. (12). Substituting the equilibrium locations for $l_2>l_1$ and $l_2-\sqrt{t}/2t \leq 0$, the condition for t is $36/49 \geq t>1/2$.

(iv) If $t<1/2$, $\partial \Pi_1/\partial l_1>0$ and $\partial \Pi_2/\partial l_2<0$. Then, the equilibrium locations are $l_1^*=l_2^*=1/2$.

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（相浦　洋志，E-mail: aiura@nanzan-u.ac.jp）