Appendix (not for publication)

We explain the calculation to derive Proposition 2 in Section 4.1. There are four cases depending on the pricing strategies set by the firms. We discuss each of the four cases.

UP-UP When both firms employ UP, the indifferent consumer, $\hat{x}_{uu}$, is given as

$$q_1 - p_1 - t\hat{x}_{uu} = q_2 - p_2 - t(1-\hat{x}_{uu}) \quad \rightarrow \quad \hat{x}_{uu} = \frac{t + q_1 - q_2 + p_2 - p_1}{2t}.$$

The profits are given by

$$\pi_1 = (p_1 - c)\hat{x}_{uu}, \quad \pi_2 = (p_2 - c)(1-\hat{x}_{uu}).$$

The first-order conditions lead to

$$p_i = \frac{3t + 3c + q_i - q_j}{3}, \quad \hat{x}_{uu} = \frac{3t + q_1 - q_2}{6t}, \quad \pi_i = \frac{(3t + q_i - q_j)^2}{18t}.$$

By substituting $q_1 = v + d + e_1$ and $q_2 = v + e_2$ into π_i, we have

$$\pi_1 = \frac{(3t + d + e_1 - e_2)^2}{18t}, \quad \pi_2 = \frac{(3t - d - e_1 + e_2)^2}{18t}.$$

The profits are equivalent with those under 'No firm employs TP' in Section 4.1 except the effort costs, γe_i^2.

UP-TP Consider the case in which firm 1 employs UP and firm 2 employs TP. We can apply the discussion of this case to that in which firm 2 employs UP and firm 1 employs TP. When only firm 1 employs UP, the timing is as follows. First, firm 1 sets its price. Second, observing this price, firm 2 sets its prices.

Given that firm 1 sets its price p_1, firm 2 takes the demand of consumer x if and only if

$$q_1 - p_1 - tx < q_2 - p_2(x) - t(1-x) \quad \rightarrow \quad p_2(x) < q_2 - q_1 + p_1 + t(2x-1).$$

If the right-hand side in the latter inequality is larger than the marginal cost of firm 2, c_2, it sets $p_2(x)$ at $q_2 - q_1 + p_1 + t(2x-1) - \varepsilon$ to take the demand of consumer x, where ε is sufficiently small; we omit this value. Otherwise, it sets $p_2(x)$ at c_2. The optimal price of firm 2 at point x is given by

$$p_2(x) = \begin{cases} q_2 - q_1 + p_1 + t(2x-1) & \text{if } c < q_2 - q_1 + p_1 + t(2x-1), \\ c & \text{otherwise.} \end{cases}$$

The indifferent consumer $\hat{x}_{ut}$ is given by

$$c = q_2 - q_1 + p_1 + t(2x-1) \quad \rightarrow \quad \hat{x}_{ut} = \frac{t + c + q_1 - q_2 - p_1}{2t}.$$

Anticipating the prices of firm 2, firm 1 sets its price, p_1. The profit of firm 1 is given by

$$\pi_1 = (p_1 - c)\hat{x}_{ut} = \frac{(p_1 - c)(t + c + q_1 - q_2 - p_1)}{2t}.$$

The first-order condition leads to

$$p_1 = \frac{t + 2c + q_1 - q_2}{2}, \quad \hat{x}_{ut} = \frac{t + q_1 - q_2}{4t}, \quad \pi_1 = \frac{(t + q_1 - q_2)^2}{8t}.$$

The profit of firm 2 is given by

$$\pi_2 = \int_{\hat{x}_{ut}}^{1} (q_2 - q_1 + p_1 + t(2m-1) - c)dm = \frac{(3t + q_2 - q_1)^2}{16t}.$$

By substituting $q_1 = v + d + e_1$ and $q_2 = v + e_2$ into π_i, we have

$$\pi_1 = \frac{(t + d + e_1 - e_2)^2}{8t}, \quad \pi_2 = \frac{(3t + e_2 - d - e_1)^2}{16t}.$$

The profits are equivalent with those under 'Only firm 2 employs TP' in Section 4.1 except the effort costs, γe_i^2.

Conversely, under the case in which firm 2 employs UP and firm 1 employs TP, the profits of the firms are given by

$$\pi_1 = \frac{(3t + q_1 - q_2)^2}{16t}, \quad \pi_2 = \frac{(t + q_2 - q_1)^2}{8t}.$$

By substituting $q_1 = v + d + e_1$ and $q_2 = v + e_2$ into π_i, we have

$$\pi_1 = \frac{(3t + d + e_1 - e_2)^2}{16t}, \quad \pi_2 = \frac{(t + e_2 - d - e_1)^2}{8t}.$$

The profits are equivalent with those under 'Only firm 1 employs TP' in Section 4.1 except the effort costs, γe_i^2.

TP-TP When both firms employ TP, the lowest price of firm i for each consumer is c. Firm 1 takes the demand of consumer x if and only if

$$q_1 - p_1(x) - tx > q_2 - c - t(1 - x) \quad \to \quad p_1(x) < q_1 - q_2 + c + t(1 - 2x).$$

If the right-hand side in the latter inequality is larger than the marginal cost of firm 1, c, it sets $p_1(x)$ at $q_1 - q_2 + c + t(1 - 2x) - \varepsilon$ to take the demand of consumer x, where ε is sufficiently small; we omit this value. Otherwise, it sets $p_1(x)$ at c. The optimal price of firm 1 at point x is given by

$$p_1(x) = \begin{cases} q_1 - q_2 + c + t(1 - 2x) & \text{if } q_2 < q_1 + t(1 - 2x), \\ c & \text{otherwise.} \end{cases}$$

A similar argument is applied to the prices of firm 2.

$$p_2(x) = \begin{cases} q_2 - q_1 + c + t(2x - 1) & \text{if } q_1 < q_2 + t(2x - 1), \\ c & \text{otherwise.} \end{cases}$$

The indifferent consumer $\hat{x}_{tt}$ is given by

$$q_1 - c - tx = q_2 - c - t(1-x) \quad \rightarrow \quad \hat{x}_{tt} = \frac{t + q_1 - q_2}{2t}.$$

The profits of the firms are given by

$$\pi_1 = \int_0^{\hat{x}_{tt}} (q_1 - q_2 + c + t(1-2m) - c) dm = \frac{(t + q_1 - q_2)^2}{4t},$$
$$\pi_2 = \int_{\hat{x}_{tt}}^1 (q_2 - q_1 + c + t(2m-1) - c) dm = \frac{(t + q_2 - q_1)^2}{4t}.$$

By substituting $q_1 = v + d + e_1$ and $q_2 = v + e_2$ into π_i, we have

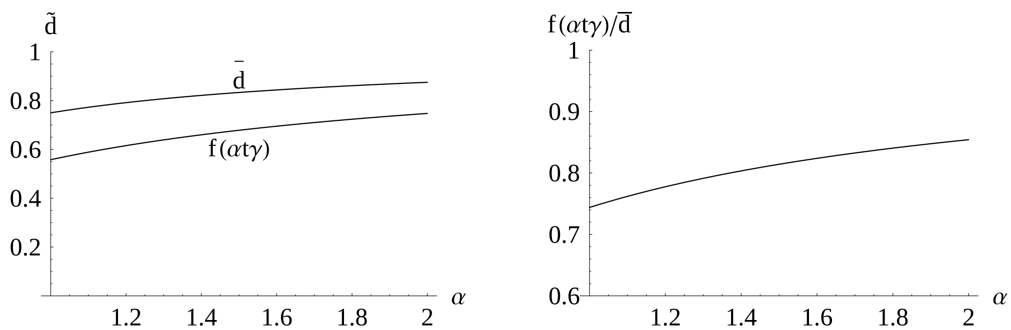
$$\pi_1 = \frac{(t + d + e_1 - e_2)^2}{4t}, \quad \pi_2 = \frac{(t + e_2 - d - e_1)^2}{4t}.$$

The profits are equivalent with those under 'Both firms employ TP' in Section 4.1 except the effort costs, γe_i^2.

We consider the case in which the effort costs to decrease the marginal cost depend on the decision of pricing policy. We only mention the additional assumption on the model in Section 4.1. We assume that $I(e_i) = \alpha\gamma e_i^2$ if firm i employs TP, where $\alpha > 1$. That is, the effort cost under TP is larger than that under UP. Employing TP requires more skills for the firm. This higher requirement level is also applied to the effort cost under TP. We therefore assume that $\alpha > 1$. To guarantee that the second-order conditions for cost-reducing activities are satisfied, we assume that $\alpha t\gamma \geq 1$. The timing structure of the game is the same as in the previous subsection.

The decision of firm 2 to employ TP depends on the *ex ante* cost difference between the firms, $\tilde{d}$, as depicted in Figure 1. The threshold value of $\tilde{d}$ depends not only on $t\gamma$ but also on the difficulty of cost reduction under TP, α. Denote the threshold value by $f(\alpha t\gamma)$. We have the following result.

Result. *(i) Firm 1 always employs TP, and firm 2 does if and only if $\tilde{d} < f(\alpha t\gamma)$. (ii) $f(\alpha t\gamma)$ is* increasing *in α.*

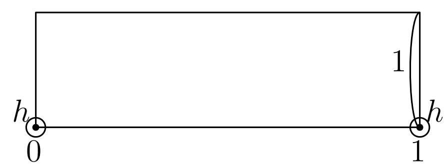


Threshold value of $\tilde{d}$, $f(\alpha t\gamma)$.

Note: We fix $t\gamma$ at 2 for presentation. $\bar{d}$ is the upper bound of $\tilde{d}$.

This means that as cost reduction under TP becomes more difficult, firm 2's incentive to employ TP increases (see Figure). As explained earlier, the key point of our model is that the employment of TP by firm 2 enhances the incentive of firm 1 for cost-reducing activity given that firm 1 employs TP. An increase in the difficulty of cost reduction (an increase in α) weakens this strategic reaction of firm 1 to firm 2's adoption of TP, which enhances the incentive of firm 2 to employ TP.

We investigate the demand structure under which “UP–UP” appears in equilibrium. We consider the following distribution of consumers on a linear city. Consumers are uniformly distributed along the unit interval $[0, 1]$, and the density of the consumer distribution is 1. Two masses of consumers exist at the points 0 and 1, respectively. The size of each mass is h, where h is a positive constant. The following figure shows the distribution of consumers.



The distribution of consumers

Firm 1 is located at 0 and firm 2 is located at 1. Each consumer buys exactly one unit of the good, which can be produced by either firm 1 or firm 2. A consumer locating at $x \in [0, 1]$ incurs a transportation cost of tx $[t(1 - x)]$ when purchasing a product from firm 1 (firm 2), where t is a positive constant. Each consumer derives a surplus from consumption (i.e., the gross of price and transportation costs) equal to v. We assume that v is so large that every consumer consumes one unit of the product. In this model setting, we do not consider the cost-reducing efforts of firms. We assume that the marginal cost of each firm is c, where c is a positive constant.

First, we consider the case in which both firms employ UP. Suppose that the difference between the prices is small, such that the location of indifferent consumers is on the $(0, 1)$ interval, that is,

$$0 < \frac{t + p_2 - p_1}{2t} < 1.$$

After we derive the equilibrium prices, we check whether the firms do not have an incentive to change their prices given the equilibrium prices.

The profit of firm i is given as

$$\pi_i = (p_i - c)\left(h + \frac{t + p_j - p_i}{2t}\right), \quad i, j = 1, 2, \ j \neq i. \tag{1}$$

The best response and the equilibrium prices are given as

$$p_i(p_j) = \frac{c + (1 + 2h)t + p_j}{2}, \quad p_i^* = c + (1 + 2h)t.$$

The equilibrium profit of each firm is

$$\pi_i^* = \frac{(1 + 2h)^2 t}{2}.$$

We show the condition whereby no firm has an incentive to change its price given the equilibrium prices. The profit function in (1) does not consider that the demand for firm i discontinuously changes around p_i such that

$$\frac{t + p_j - p_i}{2t} = 1 \quad or \quad p_i = p_j - t.$$

More concretely, the demand for firm i, D_i, is given as

$$D_i = \begin{cases} h + (t + p_j - p_i)/(2t) & \text{if } p_i \in (p_j - t, p_j + t), \\ h + 1 + h/2 & \text{if } p_i = p_j - t, \\ h + 1 + h & \text{if } p_i < p_j - t. \end{cases}$$

For $p_i \in (p_j - t, p_j + t)$, the profit function in (1) continuously changes with a reduction in p_i. The local optimum for $p_i \in (p_j - t, p_j + t)$ is p_i^*. For $p_i \leq p_j - t$, the local optimum is (the superscript D indicates the deviation from the equilibrium price, p_i^*)

$$p_i^D = c + 2ht - \varepsilon,$$

where ε is positive and sufficiently small. The profit of firm i is given as

$$\pi_i^D = (2ht - \varepsilon)(1 + 2h).$$

The equilibrium profit is larger than the deviation profit if and only if

$$h \leq \frac{1}{2} + \frac{\varepsilon}{t}. \tag{2}$$

The right-hand side in (2) is larger than 1/2.

Second, we consider the case in which one of the firms employs TP. Without loss of generality, we suppose that firm 2 employs TP. As in the main text, anticipating the best reply by firm 2, firm 1 sets its price p_1. The demand for firm 1 (i.e., the location of indifferent consumers) is given as

$$-p_1 - tx = -c - t(1-x) \quad \rightarrow \quad x = \frac{t + c - p_1}{2t}.$$

The profit of firm 1 is given as

$$\pi_1 = (p_1 - c)\left(h + \frac{t + c - p_1}{2t}\right).$$

The first-order condition leads to

$$p_1^{**} = c + \frac{(1+2h)t}{2}, \quad \pi_1^{**} = \frac{(1+2h)^2 t}{8}.$$

The equilibrium location of indifferent consumers, x^{**}, is given as

$$x^{**} = \frac{t + c - p_1^{**}}{2} = \frac{1-2h}{4}.$$

For $h \geq 1/2$, firm 1 sets the supremum of p_1 that satisfies

$$p_1 < c + t.$$

We set it using $\tilde{p}_1^{**} \equiv c + t - \varepsilon$. This price prevents firm 2 from getting all the demand, and, then, firm 2 supplies consumers located at $x > 0$. The profit of firm 1 is

$$\tilde{\pi}_1^{**} = (t - \varepsilon)h.$$

When $h < 1/2$, the profit of firm 2 is given as

$$\pi_2^{**} = \int_{x^{**}}^{1} (p_1^{**} + tm - t(1-m) - c)dm + (p_1^{**} + t - c)h = \frac{(3+2h)(3+10h)t}{16}.$$

When $h \geq 1/2$, the profit of firm 2 is given as

$$\pi_2^{**} = \int_0^1 (\tilde{p}_1^{**} + tm - t(1-m) - c)dm = 2t - \varepsilon.$$

π_i^* is larger than π_2^{**} if and only if

$$h \geq \frac{-2t + \sqrt{16t^2 - 8\varepsilon t}}{4t}. \tag{3}$$

The right-hand side in (3) is smaller than 1/2. From (2) and (3), if h satisfies the two inequalities, both firms employ UP.