Profit-reducing fixed-price contract: The role of the transport sector

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18 May 2016

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May 18, 2016

Abstract

We show that under a fixed-price contract where an upstream firm first sets the input price and downstream firms subsequently invest in R&D, all firms can become *worse off* when considering two-way trade with firm-specific carriers.

Key words: Fixed-price contract; Firm-specific carriers; R&D; Two-way trade

JEL classification: F12; L13; O31; R40

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1 Introduction

In a vertical production structure, the downstream firms' innovation can enable an upstream firm's opportunistic behavior. For example, a downstream firms' R&D efforts to improve efficiency enhance input-demand for their trading upstream firms, allowing them to raise their input prices.

To overcome this opportunistic behavior, researchers often emphasize that a fixed-price contract in which the upstream firm first sets the input price and commits not to change the price after the downstream R&D is required. This long-term input-price contract can lead to lower input price and larger investments, and thus, brings higher profit for all firms (Banerjee and Lin, 2003; Zikos and Kesavayuth, 2010).

However, this proposition may not hold when a lower input price does not bring a substantial efficiency improvement. For example, if a lower input price yields excessive investments by downstream firms, causing a loss in their profits while not sufficiently enhancing their input-demand, there is a possibility that the long-term input-price contract works negatively for both upstream and downstream firms.

Our objective is to examine the argument of input-price contract with downstream R&D in the context of international trade with transportation. Considering a long-distance trade, transportation is an essential input for exporting firms to convey their products, and the transport-price is an important factor which affects innovation through market access and competition.[1] To conclude, in a two-country trade model with firm-specific carriers, the fixed-price contract of transport price can make all firms *worse*

[1]It is well-known that trade and transport costs affect innovative activity of producers through market access and competition. See, for example, Aghion et al. (2004).

off. In our setting, each country's downstream firm freely supplies to the domestic market, while it pays the transport price for a firm-specific carrier to export. The export is less efficient compared with domestic supply. Since a lower transport price promotes inefficient exports, the fixed-price contract reduces the downstream firms' profit. Further, lower transport price does not sufficiently enhance transport-demand and the fixed-price contract can reduce the carrier's profit.

This paper is related to works on input-price contract with downstream R&D (Banerjee and Lin, 2003; Kesavayuth and Zikos, 2009; Zikos and Kesavayuth, 2010). Banerjee and Lin (2003) show that fixed-price contract makes all firms better off. Zikos and Kesavayuth (2010) confirm that the Banerjee–Lin's result holds even if R&D spillovers exist. Kesavayuth and Zikos (2009) examine the role of R&D spillovers and the importance of wage (input price) for labor unions on an endogenous choice of contract forms of wage by union–firm pair. However, these analyses are limited to the domestic market and do not consider international trade and transportation.

Works studying international transportation[2] with downstream R&D[3] (Takauchi, 2015a, b) are also closely related. In a duopoly trade model with a monopoly carrier, Takauchi (2015a) examines the effects of efficient R&D technology on firms' profits. Takauchi (2015b) investigates the effects of R&D spillovers, carriers' transport

[2]There are other studies that consider transportation in international oligopoly (Abe et al., 2014; Ishikawa and Tarui, 2015; Matsushima and Takauchi, 2014). While Abe et al. (2014) examine the effects of upstream emission tax and downstream tariff, Ishikawa and Tarui (2015) focus on the logistics problem of the carrier's roundtrips and examine the effects of several trade policies. Matsushima and Takauchi (2014) consider the effect of privatization of a sea-port on its usage fee (trade barrier) and welfares.

[3]Ghosh and Lim (2013), Haaland and Kind (2008), and Long et al. (2011) consider the relationship between trade costs and innovation without upstream agents. They examine the effects of an exogenous trade cost reduction on firms and industrial investments.

efficiency, and competition in the upstream transport market on innovation and welfares under a similar two-country trade model. Although these studies focus on the transportation with downstream R&D, they do not consider input-price contracts by upstream agents.

The rest of the paper proceeds as follows. Section 2 offers the model. Section 3 derives the outcomes and compares those between two input-price schemes. All proofs are depicted in the appendix.

2 Model

We consider a duopolistic two-way trade model with firm-specific carriers, as in Takauchi (2015a, b). There are two symmetric countries, H and F, which have a homogeneous product market. Each country has a single producing firm (called *firm* i, $i = H, F$) and a firm-specific carrier (called *carrier* i). While firm i freely supplies to the domestic market, it must use carrier i and pay a per-unit transport price, t_i, to export. Before production, firms engage in cost-reducing R&D competition without spillovers. The profit of firm i is given by

$$\Pi_i \equiv (a - q_{ii} - q_{ji} - (c - x_i))q_{ii} + (a - q_{jj} - q_{ij} - (c - x_i) - t_i)q_{ij} - \gamma x_i^2, \qquad (1)$$

where q_{ii} is firm i's domestic supply, q_{ij} is i's export, q_{ji} is firm j's export, x_i is firm i's investment level, γx_i^2 is the R&D cost, and $i \neq j; i, j = H, F$; $a, c, \gamma > 0$ and $a - c > 0$. The carrier i makes a take-it-or-leave-it offer to firm i and decides its price. Each carrier's profit is $\pi_i \equiv t_i q_{ij}$.[4]

We compare outcomes between two input-price schemes.[5] The first is a *fixed-price contract* where each carrier first sets its transport price and the firms subsequently invest; the second is a *floating price contract* where firms first invest and each carrier subsequently sets its price. In all these, each firm decides its outputs in the final stage of the game and competes *à la* Cournot at both markets in H and F. The game is solved by backward induction.

3 Results

In the final-stage, each firm decides outputs to maximize its profit. The first-order conditions for profit maximization are $\partial \Pi_i / \partial q_{ii} = \alpha - 2q_{ii} - q_{ji} + x_i = 0$ and $\partial \Pi_i / \partial q_{ij} = \alpha - 2q_{ij} - q_{jj} + x_i - t_i = 0$, where $\alpha \equiv a - c$. These yield $q_{ii}(t_j, \mathbf{x}) = (\alpha + t_j + 2x_i - x_j)/3$ and $q_{ij}(t_i, \mathbf{x}) = (\alpha - 2t_i + 2x_i - x_j)/3$. Let $\mathbf{x} = (x_i, x_j)$.

In the fixed-price contract, each firm chooses an investment level at the second stage. The second-stage investment level is $x_i(\mathbf{t}) = \frac{4(3\gamma-4)\alpha - 4(3\gamma-2)t_i + 6\gamma t_j}{(3\gamma-4)(9\gamma-4)}$, where $\mathbf{t} = (t_i, t_j)$. This yields the equilibrium transport price:

$$t_i^{fx} = \frac{9\gamma(3\gamma - 4)\alpha}{4(3\gamma - 1)(9\gamma - 10)}. \tag{2}$$

The outcome in the fixed-price contract is labeled "*fx*." From (2), we have the outcomes

[4]Our main result does not alter even though the other trade cost τ exists (i.e., $\pi_i \equiv (t_i - \tau)q_{ij}$).

[5]Even if we consider a simultaneous move where firm's investment and carrier's transport price are simultaneously decided, our main result does not change. Therefore, for simplicity, we omit the case of simultaneous move.

in the fixed-price contract:

$$
\begin{aligned}
q_{ii}^{fx} &= \frac{3\gamma(135\gamma^2-210\gamma+64)\alpha}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)}; \quad q_{ij}^{fx} = \frac{3\gamma(9\gamma-8)\alpha}{2(9\gamma-10)(9\gamma-4)},\\
x_i^{fx} &= \frac{(189\gamma^2-276\gamma+80)\alpha}{2(3\gamma-1)(9\gamma-10)(9\gamma-4)}; \quad \pi_i^{fx} = \frac{27\gamma^2(3\gamma-4)(9\gamma-8)\alpha^2}{8(3\gamma-1)(9\gamma-10)^2(9\gamma-4)},\\
\Pi_i^{fx} &= \frac{\gamma(190269\gamma^5-717336\gamma^4+1024488\gamma^3-686592\gamma^2+215808\gamma-25600)\alpha^2}{16(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2}. \qquad (3)
\end{aligned}
$$

To ensure a positive quantity, we assume that $\gamma > 4/3$.[6]

In a similar manner as in the above, we obtain the outcome in the floating price contract.

$$
\begin{aligned}
q_{ii}^{l} &= \frac{60\gamma\alpha}{144\gamma-43}; \quad q_{ij}^{l} = \frac{24\gamma\alpha}{144\gamma-43}; \quad x_i^{l} = \frac{43\alpha}{144\gamma-43},\\
t_i^{l} &= \frac{36\gamma\alpha}{144\gamma-43}; \quad \pi_i^{l} = \frac{864\gamma^2\alpha^2}{(144\gamma-43)^2}; \quad \Pi_i^{l} = \frac{\gamma(4176\gamma-1849)\alpha^2}{(144\gamma-43)^2}. \qquad (4)
\end{aligned}
$$

The outcome in the floating price contract is labeled "l."

From (2)-(4), we obtain Lemmas 1–3.

Lemma 1. *(i)* $t_i^l > t_i^{fx}$. *(ii)* $\partial t_i^{fx}/\partial\gamma \leq (>)\ 0$ *if* $\gamma \geq (<)\ 2\big(\sqrt{15}+5\big)/3 \simeq 5.91532$*;* $\partial t_i^l/\partial\gamma < 0$.

Lemma 2. $x_i^{fx} > x_i^l$.

Lemma 3. *(I) For the export,* $q_{ij}^{fx} > q_{ij}^l$. *(II) For the domestic supply, (i)* $q_{ii}^l > q_{ii}^{fx}$ *if* $\gamma < \big(\sqrt{23521}+239\big)/225 \simeq 1.74385$ *and* $q_{ii}^{fx} \geq q_{ii}^l$ *if* $\gamma \geq \big(\sqrt{23521}+239\big)/225$*; (ii)* $\partial q_{ii}^{fx}/\partial\gamma \leq (>)\ 0$ *if* $\gamma \geq (<)\ \gamma_{dq} \simeq 1.48449$*, and* $\partial q_{ii}^l/\partial\gamma < 0$.

Part (i) of Lemma 1 is intuitive. In the fixed-price contract, each carrier sets its price

[6] As long as this assumption holds, the second-order conditions for the profit maximization of carriers and firms are satisfied.

in the first stage of the game and offers lower price to raise transport-demand. In the floating price contract, the transport-price setting does not directly affect investments, and thus, the transport price becomes higher (Panel (a) of Fig. 1).

Lemma 2 is intuitively explained as follows. A lower transport price encourages investment thorough a reduction in export costs. In the fixed-price (floating price) contract, the investment is larger (smaller) because the export cost is lower (higher) (Panel (b) of Fig. 1).

The rationale behind Part (I) of Lemma 3 is as follows. A lower transport price raises exports, and hence, the export in the fixed-price contract is larger than that in the floating price contract (Panel (d) of Fig. 1). On the one hand, the domestic supply has a different feature from that of exports (Part (II) of Lemma 3). In the fixed-price contract, the rival's export is the most aggressive; it crowds out the domestic supply. The domestic supply decreases as γ goes below a certain level, because a smaller γ sharply raises exports.[7] Therefore, the domestic supply in the fixed-price contract can become smaller than that in the floating price contract (Panel (c) of Fig. 1). However, the transport price does not directly affect investments in the floating price contract: the usual result holds ($\partial q_{ii}^{l}/\partial\gamma < 0$).

Finally, we consider Part (ii) of Lemma 1. A smaller γ corresponds to lower R&D-cost and higher R&D incentives. Thus, carriers reduce the transport price to cause further investments and exports as γ decreases. In the floating price contract, the transport price rises as γ decreases because the transport-price setting does not directly

[7] In fact, $\partial q_{ij}^{k}/\partial\gamma < 0$ holds for $k = fx, l$.

affect investments.

(3) and (4) yield Proposition.

Proposition. *(i)* $\pi_i^l > \pi_i^{fx}$ *if* $\gamma < \gamma^* \simeq 1.74661$*;* $\pi_i^{fx} > \pi_i^l$ *if* $\gamma > \gamma^*$*. (ii)* $\Pi_i^l > \Pi_i^{fx}$*.*

Part (i) is explained as follows. In the fixed-price contract, the transport price sharply drops as γ goes below a certain level, and thus, the profit can decrease as γ decreases. For this reason, the profit in the fixed-price contract can be smaller than that in the floating price contract (Panel (a) in Fig. 2).

Part (ii) is explained by exports and investments. The export is less efficient because it requires firms to pay transport prices. While the export is the most active and the inefficiency is large in the fixed-price contract, its investment is larger than that in the floating price contract. This increases the loss, and hence, the profit in the fixed-price contract is smaller (Panel (b) in Fig. 2).

A liner quadratic production cost. When we relax the assumption of a constant marginal production cost, do the results change? To consider this, let us introduce a liner quadratic production cost: $(c - x_i)(q_{ii} + q_{ij}) + (q_{ii} + q_{ij})^2$. Although this yields an increasing marginal cost, the same result holds if γ is small enough.[8]

Acknowledgments

I thank Noriaki Matsushima for his many helpful comments. All remaining errors are my own.

[8]For more details, see Supplemental Materials.

Appendix

Proof of Lemma 1. (i) $t_i^l - t_i^{fx} = \frac{27\gamma(27\gamma-4)\alpha}{4(3\gamma-1)(9\gamma-10)(144\gamma-43)} > 0$. (ii) Differentiating t_i^k w.r.t. γ, we have $\partial t_i^l/\partial\gamma = -\frac{1548\alpha}{(43-144\gamma)^2} < 0$ and $\partial t_i^{fx}/\partial\gamma = -[9(9\gamma^2-60\gamma+40)\alpha]/[4(9\gamma-10)^2(3\gamma-1)^2]$. Thus, $\partial t_i^{fx}/\partial\gamma \leq (>)\ 0$ if $\gamma \geq (<)\ 2(\sqrt{15}+5)/3 \simeq 5.91532$. Q.E.D.

Proof of Lemma 2. $x_i^{fx} - x_i^l = \frac{9\gamma(702\gamma^2-933\gamma+248)\alpha}{2(3\gamma-1)(9\gamma-10)(9\gamma-4)(144\gamma-43)} > 0$. Q.E.D.

Proof of Lemma 3. (I) For the export, $q_{ij}^{fx} - q_{ij}^l = \frac{3\gamma(477\gamma-296)\alpha}{2(9\gamma-10)(9\gamma-4)(144\gamma-43)} > 0$.
(II) For the domestic supply, (i) $q_{ii}^l - q_{ii}^{fx} = \frac{-3\gamma(675\gamma^2-1434\gamma+448)\alpha}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)(144\gamma-43)}$. Thus, $q_{ii}^l - q_{ii}^{fx} \geq (<)\ 0$ if $\gamma \leq (>)\ (\sqrt{23521}+239)/225 \simeq 1.74385$. (ii) Differentiating q_{ii}^k w.r.t. γ, we have $\partial q_{ii}^l/\partial\gamma = -\frac{2580\alpha}{(43-144\gamma)^2} < 0$ and $\partial q_{ii}^{fx}/\partial\gamma = [-3(10935\gamma^4 - 35316\gamma^3 + 38484\gamma^2 - 16800\gamma + 2560)\alpha]/[4(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2]$. Thus, $\partial q_{ii}^{fx}/\partial\gamma \leq (>)$ if $\gamma \geq (<)\ \gamma_{dq} \simeq 1.48449$. Q.E.D.

Proof of Proposition. (i) For the carrier's profit,

$$\pi_i^{fx} - \pi_i^l = \frac{27\gamma^2(101088\gamma^3 - 285309\gamma^2 + 214692\gamma - 43232)\alpha^2}{8(3\gamma-1)(9\gamma-10)^2(9\gamma-4)(144\gamma-43)^2}.$$

Thus, $\pi_i^{fx} - \pi_i^l \leq (>)\ 0$ if $\gamma \leq (>)\ \gamma^* \simeq 1.74661$. (ii) For the firm's profit, $\Pi_i^l - \Pi_i^{fx} = \left[9\gamma^2(64350288\gamma^5 - 201615885\gamma^4 + 232580808\gamma^3 - 124344360\gamma^2 + 31260864\gamma - 2993408)\alpha^2\right]/\left[16(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2(144\gamma-43)^2\right] > 0$. Q.E.D.

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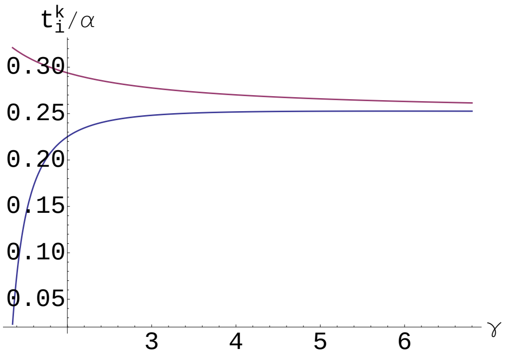
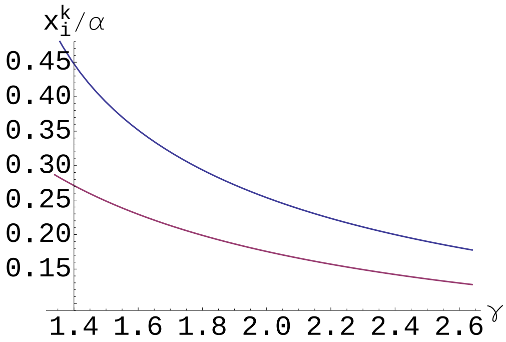
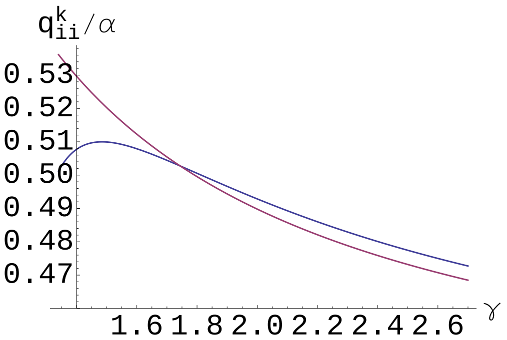


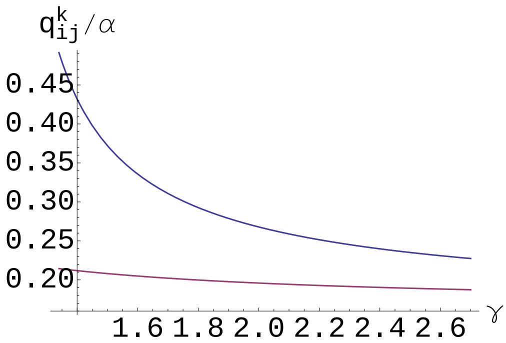
Panel (a): Transport price.



Panel (b): R&D investment.



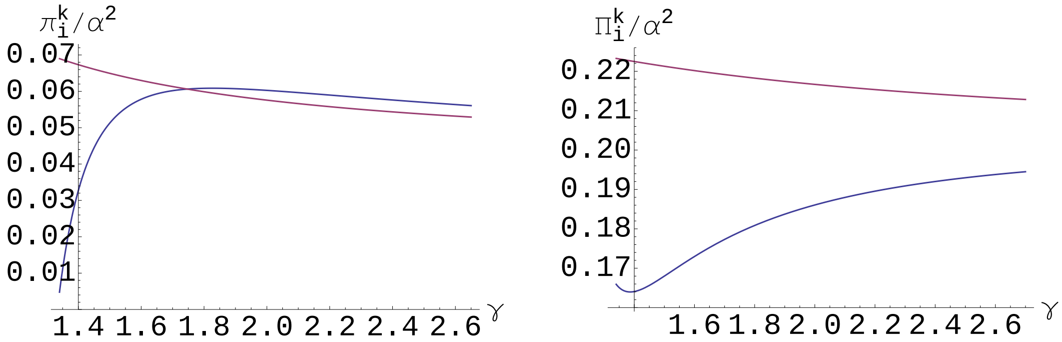
Panel (c): Domestic supply.



Panel (d): Export.

Figure 1: Illustration of Lemmas 1–3.

Note: Blue curve is $k = fx$; red curve is $k = l$.



Panel (a): Carrier's profit.

Panel (b): Firm's profit.

Figure 2: Illustration of Proposition.

Note: Blue curve is $k = fx$; red curve is $k = l$.

Supplemental Materials

Outcome in the case of linear quadratic production cost

When firms have a liner quadratic cost, that is, $(c-x_i)(q_{ii}+q_{ij})+(q_{ii}+q_{ij})^2$, the firm i's profit is rewritten as

$$\Pi_i \equiv (a-q_{ii}-q_{ji})q_{ii} + (a-q_{jj}-q_{ij}-t_i)q_{ij} - \left[(c-x_i)(q_{ii}+q_{ij}) + (q_{ii}+q_{ij})^2\right] - \gamma x_i^2.$$

FOCs for the profit maximization at the third stage of the game are $\partial\Pi_i/\partial q_{ii} = \alpha - 4q_{ii} - q_{ji} - 2q_{ij} + x_i = 0$ and $\partial\Pi_i/\partial q_{ij} = \alpha - 4q_{ij} - q_{jj} - 2q_{ii} - t_i + x_i = 0$. These yield the third-stage outputs: $q_{ii}(\mathbf{t},\mathbf{x}) = (15\alpha + 26t_i + 19t_j + 18x_i - 3x_j)/105$ and $q_{ij}(\mathbf{t},\mathbf{x}) = (15\alpha - 44t_i - 16t_j + 18x_i - 3x_j)/105$. Using these third-stage outputs and the carrier's profit, we obtain the following outcome in the fixed-price contract:

$$\begin{aligned}
\hat{q}_{ii}^{fx} &= \frac{7\gamma(182525\gamma^2 - 62370\gamma + 5184)\alpha}{4z_1}; \quad \hat{q}_{ij}^{fx} = \frac{7\gamma(385\gamma - 72)\alpha}{2(91\gamma - 18)(245\gamma - 36)},\\
\hat{x}_i^{fx} &= \frac{9(47285\gamma^2 - 15876\gamma + 1296)\alpha}{2z_1}; \quad \hat{t}_i^{fx} = \frac{21\gamma(175\gamma - 36)\alpha}{4(70\gamma - 9)(91\gamma - 18)},\\
\hat{\pi}_i^{fx} &= \frac{147\gamma^2(67375\gamma^2 - 26460\gamma + 2592)\alpha^2}{8(91\gamma - 18)z_1}; \quad \hat{\Pi}_i^{fx} = \frac{3\gamma z_2\alpha^2}{8{z_1}^2},
\end{aligned}$$

where $z_1 \equiv (70\gamma - 9)(91\gamma - 18)(245\gamma - 36) > 0$
and $z_2 \equiv 752291824375\gamma^5 - 628186595400\gamma^4 + 208285261380\gamma^3 - 34271584704\gamma^2 + 2798240256\gamma - 90699264 > 0$. Throughout this supplemental material, the variables of equilibrium outcome in all schemes are denoted by "ˆ."

By a similar procedure as in the above, we obtain the following equilibrium outcomes for the floating price contract:

$$\hat{q}_{ii}^{l} = \frac{62580\gamma\alpha}{305760\gamma - 39551}; \ \hat{q}_{ij}^{l} = \frac{18480\gamma\alpha}{305760\gamma - 39551}; \ \hat{x}_i^{l} = \frac{39551\alpha}{305760\gamma - 39551}; \ \hat{t}_i^{l} = \frac{44100\gamma\alpha}{305760\gamma - 39551},$$
$$\hat{\pi}_i^{l} = \frac{814968000\gamma^2\alpha^2}{(305760\gamma - 39551)^2}; \ \hat{\Pi}_i^{l} = \frac{\gamma(10828490400\gamma - 1564281601)\alpha^2}{(305760\gamma - 39551)^2}.$$

To ensure positive quantity, we need $\gamma > 36/175 \simeq 0.205714$.

Let us compare the profits of firms and carriers between two input-price schemes. For the firm's profit,

$$\hat{\Pi}_i^l - \hat{\Pi}_i^{fx} = \left(7\gamma^2 z_3 \alpha^2\right) / \left[8(70\gamma - 9)^2 (91\gamma - 18)^2 (245\gamma - 36)^2 (305760\gamma - 39551)^2\right] > 0,$$

where

$$z_3 \equiv 7993747235594302000 0\gamma^5 - 62581594346582185875\gamma^4 + 19417945415437018800\gamma^3 - 2985962868848785140\gamma^2 + 227661814729998432\gamma - 6888591842745600 > 0.$$

For the carrier's profit,

$$\hat{\pi}_i^{fx} - \hat{\pi}_i^l = \frac{147\gamma^2 z_4 \alpha^2}{8(70\gamma - 9)(91\gamma - 18)^2 (245\gamma - 36)(305760\gamma - 39551)^2},$$

where $z_4 \equiv 123968297544000\gamma^3 - 64288732502225\gamma^2 + 10893161153700\gamma - 601277642208$. From this, $\hat{\pi}_i^{fx} - \hat{\pi}_i^l \leq (>)\ 0$ if $\gamma \leq (>)\ \hat{\gamma} \simeq 0.212379$.

Summarizing these, we obtain the following.

Result.[9] *Suppose that firm i has a linear quadratic production cost and the R&D effort reduces its linear coefficient, that is, $(c - x_i)(q_{ii} + q_{ij}) + (q_{ii} + q_{ij})^2$. Then, a fixed-price contract by the firm-specific carrier makes carriers and firms worse off if and only if $\gamma < \hat{\gamma} \simeq 0.212379$.*

[9] Also, this result does not change even if we consider the simultaneous move of carriers and firms.