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Solving a hold-up problem may harm all firms: Downstream R&D and transport-price contracts

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Abstract

This study considers transport-price contracts in a two-country duopoly model with firm-specific carriers. It is well-known that when an upstream firm fails to commit to keeping its transaction (or transport) price after a downstream firm's R&D investment, it causes the hold-up problem and diminishes the incentive for R&D investment. While previous literature emphasizes that the commitment to keep the transaction price is needed to overcome the hold-up problem, we show that this commitment may harm all firms. We also discuss the robustness of our results in cases with R&D spillovers, product differentiation, and non-linear production costs.

Key words: Transport-price contracts; Downstream R&D; Firm-specific carrier; Hold-up problem

JEL classification: L13; F12; O31; R40

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1 Introduction

In vertical relations, research and development (R&D) investments by downstream firms give upstream agents an incentive for opportunistic behavior. Suppose that a downstream firm invests to reduce its production cost. After observing the investment activity, the upstream trading partner can extract the R&D benefit from the downstream firm by setting a higher input price. Some fear that the upstream firm *holds-up* the downstream firm's investment. Additionally, this hold up behavior by the upstream firm reduces downstream investment,[1] and hence, it tends to decrease both upstream and downstream firms' profit. Other studies find that an effective solution to this problem is to fix the input price using a long-term price agreement, that is, a *fixed-price contract* (Banerjee and Lin, 2003; Zikos and Kesavayuth, 2010). This solution is effective because if the input price is fixed under a long-term contract, the downstream firm does not need to worry about the upstream firm attempting to increase the input price.

This hold-up problem also can appear in a vertical relation between exporting and transporting firms. International transportation is an essential service to ship products overseas, and an exporting firm pays freight rates to cargo carriers to export. Hence, by setting a higher price after the exporting firm's investment, it is possible for the carrier to extract the R&D benefit.[2] Transport cost is actually a major trade barrier, at least as much as or larger than other representative policy barriers[3] and affects firms' innovation activities. For example, because a higher transport cost limits access to foreign markets and inhibits export production, it affects incentives to innovate, such as for cost-reducing R&D.[4]

[1] The importance of upstream firms' opportunistic behavior that causes downstream firms to under-invest (i.e., the hold-up problem) is widely recognized among researchers. For example, Gilbert and Cvsa (2003) give an example of a key-component supplier, such as Intel, and an investment by a PC maker, such as Dell, in the computer industry, and emphasize that this sort of hold-up problem is very likely to occur in supply chains such that downstream firms depend on their trading partners for both knowledge and capacity. Banerjee and Lin (2003) also give a similar example from the computer industry.

[2] Hummels et al. (2009) empirically show that transport prices, such as the ocean freight rate, is a mark-up price and carriers have monopoly power. This empirical evidence implies that carriers possibly extract rent from exporters thorough price setting.

[3] According to Anderson and Van Wincoop (2004), the ad-valorem tax equivalent of transport costs is 10.7%, while that of tariff and non-tariff barriers is 7% in developed nations.

[4] Factors such as market access and competitive intensity influence innovation incentives. Since

We consider a hold-up problem in international transportation and show that a fixed-price contract that resolves the problem in this transport market has entirely different effects than those found in the existing literature.

We base our model on the two-country duopoly modeled by Brander (1981) and Brander and Krugman (1983). There are two firm-specific carriers upstream and two exporters downstream. Each country has both a carrier and an exporting firm. Each carrier takes a per-unit transport charge from its domestic exporting firm and ships products to the foreign market. Each exporting firm pays a transport charge to its country's carrier in order to export, while it freely supplies to the domestic market. Suppose that in this market structure, exporters can commit to zero exports. Then, each exporting firm is a monopoly in its local market and can thus gain maximum profit. We expect that a commitment to fewer exports benefits exporters.

If the hold-up problem exists, the exporter will have a high marginal cost because their investment becomes small. Hence, the hold-up problem is equal to a commitment to fewer exports. Simultaneously, the marginal cost of domestic production also becomes large, which lowers exporters' profit. Exporters face this trade-off and benefit from the hold-up problem if the commitment effect of fewer exports due to the hold-up problem is dominant.

In our analysis, when firms do not use a fixed-price contract and exporters can commit to fewer exports, they can maximize their profit because they can create a situation close to the domestic monopoly by adjusting the transport price through their investment decision. By contrast, using a fixed-price contract minimizes the exporter's profit because carriers set a lower price to promote exporters' investments and exports become the most active. Furthermore, when the cost-reducing R&D is highly efficient, carriers profit less compared to other contract schemes because carriers set considerably lower prices to promote investment. Thus, the market structure is one where fixed-price contracts harm all firms. We also consider two other relevant topics: asymmetric contract schemes (i.e., when one country adopts a fixed-price contract and the other adopts a floating-price contract), and the case of monopoly carrier. We further discuss the robustness of our results by examining three cases: a positive spillover in

transport cost affects all of these factors, it ultimately affects a producer's innovation incentives. See, for example, Aghion et al. (2004, 2005).

R&D; horizontal differentiation between home and foreign products; and non-linear production costs of firms. We find that our main result holds in these extended cases.

Our study is closely related to Takauchi's (2015) consideration of R&D rivalry in a transport sector.[5] The author examines the effects of the technical efficiency of R&D on exporters' profit when they use a monopoly carrier to export their products, and shows that higher R&D efficiency can reduce exporters' profit. Although Takauchi (2015) shares a market structure with this work; that is, exporters freely supply to their local market while they must pay freight rates for carriers to export, we incorporate transport price contracts and examine the effects on profit and welfare.

This study is related to works on input-price contracts with downstream investment. Banerjee and Lin (2003) show that fixed-price contracts make all firms better off in a market with an upstream monopoly and a downstream oligopoly. Zikos and Kesavayuth (2010) confirm Banerjee and Lin's result, even if R&D spillovers exist. Gilbert and Cvsa (2003) consider the role of final demand uncertainty in a supply-chain with one supplier and one buyer. They show that the supplier prefers a commitment to wholesale prices if the demand fluctuations are not too large, and the buyer always profits more when the supplier makes a price commitment. Kesavayuth and Zikos (2009) examine the role of R&D spillovers and the importance of wages for labor unions on an endogenous choice of contract form for wages in a union–firm pair. However, these studies are limited to the domestic market and do not consider international trade and transportation. We believe that our analysis compliments the existing literature.

In a broader sense, our study is also connected to two strands of the literature on trade costs, innovation, and vertical structures. The first discusses the role of trade costs in an oligopoly framework, in which some consider the effects of the trade cost reduction on R&D investment (e.g., Dewit and Leahy, 2016; Ghosh and Lim, 2011; Haaland and Kind, 2008; Long et al., 2011), and others focus on the effects of trade cost reduction on firm behavior and welfare within vertical production relations (e.g.,

[5] Other studies also consider an imperfectly competitive transport sector in international trade. Francois and Wooton (2001) and Behrens et al. (2009) examine the roles of transport prices and transporting firms' market power in general equilibrium settings. Using a two-country oligopoly model, Abe et al. (2014) examine the effects of emissions tax in the transport sector, while Ishikawa and Tarui (2018) examine the effects of several trade policies on the transport market. Matsushima and Takauchi (2014) consider how seaport privatization influences their usage fees (trade cost) and welfare in an international oligopoly.

Beladi and Oladi, 2011; Liu and Mukherjee, 2013; Maiti and Mukherjee, 2013; Marjit and Mukherjee, 2015). The second strand studies of innovative activities under vertical production linkages (e.g., Beladi and Mukherjee, 2017; Matsushima and Mizuno, 2012; Mukherjee and Pennings, 2011). While these works employ different models and obtain useful insights, they do not consider input-price contracts, unlike our analysis in this study.

The rest of the paper proceeds as follows. Section 2 presents the model. Section 3 examines transport-price contracts. In Section 4, we discuss asymmetric contract schemes, the case of a monopoly carrier, and the robustness of our main result. Lastly, Section 5 concludes the paper. Note that all proofs can be found in the appendices.

2 Model

We consider a two-way trade model with firm-specific carriers, as in Takauchi (2015). Two symmetric countries, H and F, have a homogeneous product market. Each country has a single exporting firm (called *firm* i, $i = H, F$) and a firm-specific cargo carrier (called *carrier* i). The inverse market demand in country i is $p_i = a - q_{ii} - q_{ji}$ $(i, j = H, F;\ j \neq i)$, where p_i is the product price, q_{ii} is firm i's domestic supply, q_{ji} is firm j's exports, and $a > 0$. While firm i freely supplies to the domestic market, it must use carrier i and pay a per-unit transport-price, t_i, to ship its product to an overseas market. Before production, firm i invests in R&D to reduce marginal production cost c (> 0); after the investment, the marginal cost is $c - x_i$, where x_i is the investment level. We assume that the R&D cost function is γx_i^2; γ (> 0) denotes the technical efficiency in R&D.[6] Firm i's profit is given by $\Pi_i \equiv [p_i - (c - x_i)]q_{ii} + [p_j - (c - x_i) - t_i]q_{ij} - \gamma x_i^2$, where $i, j = H, F;\ j \neq i$. Carrier i makes a take-it-or-leave-it offer to firm i and decides its transport price. Each carrier's profit is $\pi_i \equiv t_i q_{ij}$.[7]

We consider three transport-price contract schemes. The first is a *fixed-price contract* where each carrier first sets its transport price and firms subsequently invest. The second is a *floating-price contract* where firms first invest and each carrier subsequently

[6] This is a popular setting. See, for example, d'Aprémont and Jacquemin (1988), Ghosh and Lim (2013), Haaland and Kind (2008), and Takauchi (2015).

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

sets its transport price. The third is a *simultaneous move* scenario where carriers and firms simultaneously decide transport prices and investment levels. In all schemes, each firm decides its output in the final stage of the game and competes *à la* Cournot in both markets in countries H and F. The game is solved by backward induction.

3 Results

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

Fixed-price contract. In the second stage, firm i chooses an investment level, x_i, taking t_i as given. From the firm's FOC, the second-stage investment level is

$$x_i(\mathbf{t}) = \frac{4(3\gamma-4)(a-c)-4(3\gamma-2)t_i+6\gamma t_j}{(3\gamma-4)(9\gamma-4)}, \quad j \neq i. \tag{1}$$

Let $\mathbf{t} = (t_i, t_j)$. From $q_{ij}(t_i,\mathbf{x})$ and (1), carrier i's maximization problem is

$$\max_{t_i} \frac{t_i[9\gamma(3\gamma-4)(a-c)-2(3\gamma-1)(9\gamma-8)t_i+8(3\gamma-1)t_j]}{3(3\gamma-4)(9\gamma-4)}.$$

This yields the following equilibrium transport price:

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

The outcome in the fixed-price contract is labeled "fx." From (2), we have the equilibrium investment and outputs:

$$x_i^{fx} = \frac{(189\gamma^2-276\gamma+80)(a-c)}{2(3\gamma-1)(9\gamma-10)(9\gamma-4)}, \tag{3}$$

$$q_{ii}^{fx} = \frac{3\gamma(135\gamma^2-210\gamma+64)(a-c)}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)}; \quad q_{ij}^{fx} = \frac{3\gamma(9\gamma-8)(a-c)}{2(9\gamma-10)(9\gamma-4)}. \tag{4}$$

The carrier's profit and the firm's profits are

$$\begin{aligned} \pi_i^{fx} &= \frac{27\gamma^2(3\gamma-4)(9\gamma-8)(a-c)^2}{8(3\gamma-1)(9\gamma-10)^2(9\gamma-4)}, \\ \Pi_i^{fx} &= \frac{\gamma(190269\gamma^5-717336\gamma^4+1024488\gamma^3-686592\gamma^2+215808\gamma-25600)(a-c)^2}{16(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2}. \end{aligned} \tag{5}$$

To ensure a positive quantity, we assume the following.[8]

[8] As long as Assumption 1 holds, the second-order conditions for the carriers' and firms' profit

Assumption 1. $\gamma > 4/3$.

Floating-price contract. In this contract scheme, carrier i decides its transport price, t_i, in the second stage of the game. The carrier's maximization problem yields the following second-stage transport price:

$$t_i(\mathbf{x}) = \frac{1}{4}(a - c - x_j + 2x_i), \quad j \neq i. \tag{6}$$

From (6) and the firm's profit, the equilibrium investment level is

$$\frac{\partial \Pi_i(\mathbf{x})}{\partial x_i} = \frac{1}{72}(43(a-c) - 22x_j - (144\gamma - 65)x_i) = 0, \ j \neq i \ \Rightarrow \ x_i^l = \frac{43(a-c)}{144\gamma - 43}. \tag{7}$$

The outcome in the floating-price contract is labeled "l." From (7), we get the following:

$$t_i^l = \frac{36\gamma(a-c)}{144\gamma - 43}, \tag{8}$$

$$q_{ii}^l = \frac{60\gamma(a-c)}{144\gamma - 43}; \quad q_{ij}^l = \frac{24\gamma(a-c)}{144\gamma - 43}, \tag{9}$$

$$\pi_i^l = \frac{864\gamma^2(a-c)^2}{(144\gamma - 43)^2}; \quad \Pi_i^l = \frac{\gamma(4176\gamma - 1849)(a-c)^2}{(144\gamma - 43)^2}. \tag{10}$$

Simultaneous move scenario. In this case, both transport prices and investments are decided in the first-stage of the game simultaneously. Eqs. (1) and (6) yield the following:

$$t_i^s = \frac{9\gamma(a-c)}{2(18\gamma - 7)}, \tag{11}$$

$$x_i^s = \frac{7(a-c)}{18\gamma - 7}, \tag{12}$$

$$q_{ii}^s = \frac{15\gamma(a-c)}{2(18\gamma - 7)}; \quad q_{ij}^s = \frac{3\gamma(a-c)}{18\gamma - 7}, \tag{13}$$

$$\pi_i^s = \frac{27\gamma^2(a-c)^2}{2(18\gamma - 7)^2}; \quad \Pi_i^s = \frac{\gamma(261\gamma - 196)(a-c)^2}{4(18\gamma - 7)^2}. \tag{14}$$

The outcome in the simultaneous move scenario is labeled "s."

From (3), (7), and (12), we obtain Proposition 1.

Proposition 1. *(i)* $x_i^{fx} > x_i^s > x_i^l$. *(ii)* $\partial x_i^k / \partial \gamma < 0$ *for all* $k \in \{fx, l, s\}$.

The logic behind part (i) is as follows. In the floating-price contract, firms first invest and carriers subsequently charge transport prices. Then, if firms invest a higher amount,

maximization are satisfied.

carriers set a higher transport price and can extract a benefit from the R&D. Hence, to keep lower transport price, firms have an incentive to make smaller investments. According to this strategic motive, the floating-price contract will have the smallest investment among all of the schemes. By contrast, carriers first charge transport prices and firms subsequently invest in the case of a fixed-price contract. Lower transport prices enhance transport demand and, can thus raise investments. As found in the second-stage investment, $x_i(\mathbf{t})$, a lower t_i increases x_i, so carrier i sets a lower transport price. The strategic motive of carrier i makes the transport price the lowest among all of the schemes. Corresponding to this low transport price, the investment level becomes the largest. On the one hand, in the simultaneous move scenario, firms cannot directly reduce transport prices by setting a smaller investment; hence, the investment is larger than that in the floating-price contract case ($x_i^s > x_i^l$). Carriers also cannot directly raise investment by setting a lower transport price; thus, the investment is smaller than that in the fixed-price contract case ($x_i^s < x_i^{fx}$).

Part (ii) is intuitive. A smaller γ improves efficiency in R&D and strengthens innovation incentives. The investment rises as γ decreases (see Fig. 1).

[Fig. 1 around here]

Eqs. (2), (8), and (11) yield Lemma 1.

Lemma 1. *(i)* $t_i^s > t_i^l > t_i^{fx}$. *(ii) If* $\gamma > \frac{2(\sqrt{15}+5)}{3} \simeq 5.91532$, $\partial t_i^{fx}/\partial\gamma < 0$, *and if* $\gamma < \frac{2(\sqrt{15}+5)}{3}$, $\partial t_i^{fx}/\partial\gamma > 0$. $\partial t_i^l/\partial\gamma < 0$ *and* $\partial t_i^s/\partial\gamma < 0$.

Part (i) has the following intuitive explanation. In the fixed-price contract, carriers commit to lower transport prices in order to increase investment, and therefore, the price in that scheme becomes the lowest. In the floating-price contract and simultaneous move scenario, the firms' investment level is a given for carriers. In these schemes, if a realized investment becomes larger, firms' production expands, incentivizing carriers to set a higher price. As shown in Proposition 1, investment in the simultaneous move scenario is larger than that in the floating-price contract, so the transport price in the simultaneous move scenario is higher than that in the floating-price contract.

We next consider part (ii). A smaller γ enhances investment incentives (Proposition 1). In the fixed-price contract, carriers can raise investments by committing to lower transport prices. If carriers reduce transport prices when γ is small enough, and hence firms' investment incentives are large enough, it is possible to further increase investments. Hence, when γ falls below a certain level, the transport price also decreases. By contrast, in a floating-price contract and simultaneous move scenario, carriers have no transport price commitment. An increase in investment due to a lower γ promotes production activities, so the transport price increases as γ decreases. Fig. 2 illustrates Lemma 1.

[Fig. 2 around here]

Eqs. (4), (9), and (13) yield Lemma 2.

Lemma 2. *I. (i)* $q_{ij}^{fx} > q_{ij}^{s} > q_{ij}^{l}$. *(ii) If* $\gamma > \frac{\sqrt{23521}+239}{225} \simeq 1.74385$, $q_{ii}^{s} > q_{ii}^{fx} > q_{ii}^{l}$ *and if* $\gamma < \frac{\sqrt{23521}+239}{225}$, $q_{ii}^{s} > q_{ii}^{l} > q_{ii}^{fx}$. *(iii)* $Q_i^{fx} > Q_i^{s} > Q_i^{l}$, *where* $Q_i^k = q_{ii}^k + q_{ji}^k$ $(j \neq i;$ $k \in \{fx, l, s\})$. *II. (i)* $\partial q_{ij}^k/\partial\gamma < 0$ *for all* k. *(ii) If* $\gamma < \hat{\gamma} \simeq 1.48449$, $\partial q_{ii}^{fx}/\partial\gamma > 0$ *and if* $\gamma > \hat{\gamma}$, $\partial q_{ii}^{fx}/\partial\gamma < 0$. $\partial q_{ii}^{l}/\partial\gamma < 0$ *and* $\partial q_{ii}^{s}/\partial\gamma < 0$. *(iii)* $\partial Q_i^k/\partial\gamma < 0$ *for all* k.

We first consider the ranking in output. Although a lower transport price promotes exports and impedes domestic supply, $t_i^s > t_i^l$ and $q_{ij}^s > q_{ij}^l$ hold. These results depend on an investment ranking of $x_i^s > x_i^l$. In the floating-price contract, firms commit to a smaller investment. This commitment lowers the degree of the production cost reduction, so it does not sufficiently promote the whole production, and hence leads to $q_{ij}^s > q_{ij}^l$ and $q_{ii}^s > q_{ii}^l$. Comparing the simultaneous move scenario with the fixed-price contract, $q_{ij}^{fx} > q_{ij}^s$ and $q_{ii}^s > q_{ii}^{fx}$. This corresponds to the fact that the transport price is the highest in the simultaneous move scenario and is the lowest in the fixed-price contract among all schemes, $t_i^s > t_i^l > t_i^{fx}$. Carriers commit to a lower transport price in the fixed-price contract. The carrier's commitment lowers the trade barrier and promotes exports. Because competition in the domestic market becomes more intense, domestic supply decreases. On the one hand, the simultaneous move scenario will have a higher transport price, which impedes exports and promotes domestic supply. From these arguments, the export ranking is $q_{ij}^{fx} > q_{ij}^s > q_{ij}^l$, and the domestic supply ranking is $q_{ii}^s > q_{ii}^l$ and $q_{ii}^s > q_{ii}^{fx}$. The ranking of total sales is intuitive. A larger investment corresponds to lower production costs. Since higher production efficiency enhances production activities, total sales rise as efficiency improves. Hence, the total sales ranking corresponds to the investment ranking.

The domestic supply ranking between the fixed-price and floating-price contracts and part II of Lemma 2 are explained as follows. A smaller γ enhances firm's innovation incentives and raises investment. Because a decrease in γ leads to a reduction in production cost, a decrease in γ increases both domestic supply and exports. However, if γ is small, the domestic supply in the fixed-price contract decreases as γ decreases. This result depends on a change in the transport price for γ. As in part (ii) of Lemma 1, when γ is small, the transport price in the fixed-price contract falls as γ decreases. A lower transport price promotes exports, increases competition in the domestic market, and decreases domestic supply. Hence, $\partial q_{ii}^{fx}/\partial\gamma > 0$ if γ is small. Furthermore, while a lower γ reduces the domestic supply in the fixed-price contract, it increases the domestic supply in the floating-price contract. Therefore, if γ is small enough, the domestic supply in the fixed-price contract can be smaller than that in the floating-price contract (see Fig. 3). For a change in γ, the change in the total sales is the same as that in investment. A rise in investment reduces production costs and improves efficiency, so total sales increase as investment increases. A smaller γ raises investment, so total sales also rise as γ decreases.

[Fig. 3 around here]

Comparing (5), (10), and (14), we establish Proposition 2.

Proposition 2. *(i)* $\Pi_i^l > \Pi_i^s > \Pi_i^{fx}$. *(ii) If* $\gamma < \gamma^* \simeq 1.74661$, $\pi_i^s > \pi_i^l > \pi_i^{fx}$, *and if* $\gamma > \gamma^*$, $\pi_i^s > \pi_i^{fx} > \pi_i^l$.

Proposition 2 implies that a better outcome for both carriers and firms can appear when carriers do not commit to a transport price level. The ranking in firm's profit inversely corresponds to the ranking in exports (see Lemma 2). This is because, in our two-way duopoly model, the prohibitive transport price level gives the highest profit for firms. That is, the profit in a domestic monopoly (there is no export) is higher than the situation with aggressive exports.[9] This result can be traced back to the reciprocal market model of Brander (1981) and Brander and Krugman (1983). In such

[9] Using the third-stage outcomes and conditions $x_j = x_i$ and $t_j = t_i$, this fact is immediately found.

Cournot duopolistic intra-industry trade, suppose that firms face a specific transport cost (or price) when they export to the rival firm's domestic market. Then, the firms' profit is U-shaped with respect to the transport cost, and the prohibitive level of the transport cost maximizes their profits. The logic behind this result is as follows. An increase in the transport cost reduces exports, but increases the domestic supply as a result of the reduction in the rival's exports. If the transport cost is low, there is not much difference between the exports and the domestic supply. In this case, the negative effect of the export reduction dominates the positive effect of the domestic supply expansion. Therefore, an increase in the transport cost reduces the profit. Conversely, if the transport cost increases above a certain level, the domestic supply becomes much larger than exports. Then, the positive effect of the domestic supply expansion is dominant. In this case, an increase in the transport cost increases the profit. Furthermore, when the transport cost is sufficiently high, exports are close to zero and each firm can enjoy a domestic monopoly. Firms are immune to competition and, hence, can set the highest price in their domestic markets, thus maximizing their profit.[10]

When firms can commit to an investment level, it is possible for them to create a situation close to a domestic monopoly because they can adjust the transport price through their investment decision. Hence, the floating-price contract is the best scheme for firms. In contrast, the carrier's price commitment adjusts the firm's investments and exports. The carrier's lower price commitment increases the aggressiveness of the firm's export activities, and it puts firms in a situation furthermost from a domestic monopoly. The fixed-price contract is the worst for firms. In the simultaneous move scenario, carriers and firms have no commitment, so the profit in that scheme is intermediate for firms (see Fig. 4).

The carrier's profit ranking depends on the transport price and export volume. In the simultaneous move scenario, the transport price is highest among all contract schemes and the exports are of intermediate size, so the profit becomes the largest among all schemes. On the one hand, profits in fixed-price and floating-price contracts can be reversed according to the degree of γ. This is because, as in Lemma 2, a smaller

[10]This is also true when firms engage in cost-reducing R&D. See, for example, Dewit and Leahy (2016), Gosh and Lim (2013), and Takauchi (2015).

γ increases exports in both schemes and raises the transport price in the floating-price contract, while it can reduce the transport price in the fixed-price contract (see Fig. 2). Then, a smaller γ increases profit in the floating-price contract. In contrast, a smaller γ decreases profit in the fixed-price contract when γ is small. If $\gamma < \gamma^*$, profit in the fixed-price contract is the worst among all contract schemes.

[Fig. 4 around here]

Welfare analysis. Country i's consumer surplus in each contract scheme is given by $CS_i^k = \left(Q_i^k\right)^2/2$, where $k \in \{fx, l, s\}$. This yields the following:

$$CS_i^{fx} = \frac{9\gamma^2(189\gamma^2-276\gamma+80)^2(a-c)^2}{32(9\gamma-4)^2(9\gamma-10)^2(3\gamma-1)^2};\ CS_i^l = \frac{3528\gamma^2(a-c)^2}{(144\gamma-43)^2};\ CS_i^s = \frac{441\gamma^2(a-c)^2}{8(18\gamma-7)^2}. \quad (15)$$

Each country's social surplus consists of consumer surplus CS_i^k, firm's profit Π_i^k, and carrier's profit π_i^k. The social surplus in each contract scheme is

$$\begin{aligned} W_i^{fx} &= \frac{\gamma(86751\gamma^4 - 251424\gamma^3 + 249120\gamma^2 - 96960\gamma + 12800)(a-c)^2}{32(9\gamma-10)^2(3\gamma-1)^2(9\gamma-4)}, \\ W_i^l &= \frac{\gamma(8568\gamma - 1849)(a-c)^2}{(144\gamma-43)^2};\quad W_i^s = \frac{7\gamma(153\gamma-56)(a-c)^2}{8(18\gamma-7)^2}. \end{aligned} \quad (16)$$

Lemma 2, (15), and (16) yield the following result.

Proposition 3. *(i)* $CS_i^{fx} > CS_i^s > CS_i^l$ *and* $W_i^{fx} > W_i^s > W_i^l$. *(ii)* $\partial CS_i^k/\partial\gamma < 0$ *and* $\partial W_i^k/\partial\gamma < 0$.

The welfare ranking corresponds to the investment ranking. When firms increase their investment level, the marginal production cost falls and efficiencies improve, which undoubtedly increases consumer surplus (Lemma 2). Because the improvement in consumer benefit is dominant, the social surplus also increases. From the welfare point of view, the best scheme is the fixed-price contract in which investment is maximized, and the worst scheme is the floating-price contract in which investment is minimized. Furthermore, a reduction in γ enhances efficiencies in R&D and raises investment, so it also increases welfares.

Joint profit maximizing investments. We further consider the case where firm i chooses its investment level to maximize joint profit between carrier i and firm i

itself, that is, $\pi_i + \Pi_i$. We define the joint profit maximizing investment level x_i^{J1} (x_i^{J2}) in the floating-price (fixed-price) contract scenario. The number behind superscript "J" denotes the stage of the game at which firms decide their investment. The joint profit maximizing investments become $x_i^{J1} = \frac{55(a-c)}{144\gamma-55}$ and $x_i^{J2} = \frac{(a-c)(256-768\gamma+459\gamma^2)}{(9\gamma-4)(64-183\gamma+108\gamma^2)}$. Comparing investments in each scenario, we have

$$x_i^{J1} - x_i^{l} = \frac{1728(a-c)\gamma}{(144\gamma-55)(144\gamma-43)} > 0; \quad x_i^{J2} - x_i^{fx} = \frac{27(a-c)\gamma(28-45\gamma+18\gamma^2)}{2(3\gamma-1)(9\gamma-10)(64-183\gamma+108\gamma^2)} > 0.$$

When joint profit is maximized, because firm i accounts for carrier i's profit, the incentive for the firm to offer a smaller investment to reduce the transport price weakens. Consequently, $x_i^{J1} > x_i^{l}$ holds. Additionally, an expansion in investment raises the carrier's profit through an increase in the transport demand. Thus, $x_i^{J2} > x_i^{fx}$ holds.

Remark 1. *Let the joint profit maximizing investment level in the floating-price (fixed-price) contract scenario be x_i^{J1} (x_i^{J2}). Then, $x_i^{J2} > x_i^{fx}$ and $x_i^{J1} > x_i^{l}$.*

4 Discussion

In this section, we first discuss the case in which a different contract type is applied in each country. We next consider the case in which the carrier is a monopoly. We also examine the robustness of Proposition 2. Here, we first relax the assumption of no R&D spillovers and examine the case of a positive spillover. Next, we examine the case of domestic and foreign product differentiation. Finally, we introduce two types of non-linear production cost terms.

4.1 Asymmetric contract schemes

We begin by considering the situation in which the transport-price contracts in two countries differ; that is, country H adopts a fixed-price (floating-price) contract and country F adopts a floating-price (fixed-price) contract. In this environment, if firms H and F can choose either a fixed-price contract or a floating-price contract in the first stage of the game, the only equilibria that appear are those consisting of a fixed-price contract scheme (all firms choose the fixed-price contract, labeled "fx") and a floating-price contract scheme (all firms choose a floating-price contract, labeled "l"). The outcomes in asymmetric contract schemes and the derivation of the multiple equilibria can be found in Appendix B.

Figs. 5–7 illustrate the equilibrium outcomes in common contract schemes (fx and l) and asymmetric contract schemes ((l, fx) and (fx, l)).

[Figs. 5–7 around here]

Firms H and F are symmetric. Therefore, we focus on firm H. Suppose that firm H deviates from l. Then, because carrier H commits to a lower price, firm H's investment increases owing to the increase in its exports ($t_H^{fx,l} < t_H^l$, $q_{HF}^{fx,l} > q_{HF}^l$, and $x_H^{fx,l} > x_H^l$; see Figs. 5–7). However, this increase in investment corresponds to an expansion of less-efficient production activity (i.e., exports). Hence, firm H's profit decreases[11] ($\Pi_H^{fx,l} < \Pi_H^l$; see Fig. 5).

We next examine firm H's deviation from fx. In (l, fx), because firm H's investments and carrier F's transport price are given for carrier H, it sets a higher price. This high t_H weakens the innovation incentive of firm H through the reduction in its exports, which increases firm F's investment.

In the first stage of the game, firm H implements a smaller investment, but this increases firm F's investment through the strategic substitutability of R&D rivalry. On the one hand, to increase firm F's investment, carrier F must set a lower price. However, firm F's investment expands owing to a high t_H and the small investment of firm H. Therefore, carrier F can set a higher price compared to the case fx ($t_F^{l,fx} > t_F^{fx}$; see Fig. 6).

A high t_H reduces firm H's exports and increases firm F's domestic supply. Because carrier F commits to a transport price, t_F is lower than t_H ($t_F^{l,fx} < t_H^{l,fx}$; see Fig. 6). Hence, in firm H's domestic market, the exports of firm F become large and firm H's domestic supply is smaller than that of firm F ($q_{HH}^{l,fx} < q_{FF}^{l,fx}$; see Fig. 7). Therefore, the domestic supply of firm H does not necessarily become larger compared to that in the case of fx (see Fig. 7).

In summary, if firm i deviates from fx, the transport price t_i increases and, hence, its exports decrease. Furthermore, this deviation does not necessarily increase firm i's

[11] If firm H deviates from l, because carrier H commits to a lower transport price, firm H's exports increase ($q_{HF}^{fx,l} > q_{HF}^l$). This lower price commitment by carrier H increases firm H's exports sharply and, hence, the profit of carrier H increases ($\pi_H^{fx,l} > \pi_H^l$; see Fig. 5).

domestic supply. As a result, firm i's total output (the sum of exports and domestic supply) decreases[12] and, therefore, its profit decreases[13] ($\Pi_H^{l,fx} < \Pi_H^{fx}$; see Fig. 5).

4.2 Monopoly carrier

Here, we consider a situation in which a monopoly carrier conveys two firms' products. To export their products to the rival firm's domestic market, firms H and F pay the common transport price, t_m, to the monopoly carrier. Hence, the profit of the monopoly carrier is $\pi \equiv t_m(q_{HF} + q_{FH})$. It is enough to replace carrier i's transport price t_i ($i = H, F$) with the monopoly transport price t_m in the equation of firm i's profit Π_i. Thus, we obtain the following equilibrium outcomes in a similar manner to those described in the previous section. The variable with "~" denotes the equilibrium outcomes in the monopoly carrier case.

The outcomes in the fixed-price contract are

$$\tilde{t}_m^{fx}=\frac{3\gamma(a-c)}{4(3\gamma-1)};\ \tilde{x}_i^{fx}=\frac{(21\gamma-8)(a-c)}{2(3\gamma-1)(9\gamma-4)};\ \tilde{q}_{ii}^{fx}=\frac{9\gamma(5\gamma-2)(a-c)}{4(3\gamma-1)(9\gamma-4)};\ \tilde{q}_{ij}^{fx}=\frac{3\gamma(a-c)}{2(9\gamma-4)},$$
$$\tilde{\pi}^{fx} = \frac{9\gamma^2(a-c)^2}{4(3\gamma-1)(9\gamma-4)};\ \tilde{\Pi}_i^{fx} = \frac{\gamma(2349\gamma^3 - 3600\gamma^2 + 1704\gamma - 256)(a-c)^2}{16(9\gamma-4)^2(3\gamma-1)^2}.$$

The outcomes in the floating-price contract are

$$\tilde{t}_m^{l} = \frac{72\gamma(a-c)}{288\gamma-113};\ \tilde{x}_i^{l} = \frac{113(a-c)}{288\gamma-113};\ \tilde{q}_{ii}^{l} = \frac{120\gamma(a-c)}{288\gamma-113};\ \tilde{q}_{ij}^{l} = \frac{48\gamma(a-c)}{288\gamma-113},$$
$$\tilde{\pi}^{l} = \frac{6912\gamma^2(a-c)^2}{(288\gamma-113)^2};\ \tilde{\Pi}_i^{l} = \frac{\gamma(16704\gamma-12769)(a-c)^2}{(288\gamma-113)^2}.$$

The outcomes in the simultaneous move scenario are

$$\tilde{t}_m^{s} = \frac{9\gamma(a-c)}{2(18\gamma-7)};\ \tilde{x}_i^{s} = \frac{7(a-c)}{18\gamma-7};\ \tilde{q}_{ii}^{s} = \frac{15\gamma(a-c)}{2(18\gamma-7)};\ \tilde{q}_{ij}^{s} = \frac{3\gamma(a-c)}{18\gamma-7},$$
$$\tilde{\pi}^{s} = \frac{27\gamma^2(a-c)^2}{(18\gamma-7)^2};\ \tilde{\Pi}_i^{s} = \frac{\gamma(261\gamma-196)(a-c)^2}{4(18\gamma-7)^2}.$$

These equilibrium outcomes yield Proposition 4.

[12] That is, $(q_{HH}^{fx} + q_{HF}^{fx}) > (q_{HH}^{l,fx} + q_{HF}^{l,fx})$ holds. See Appendix B.

[13] When firm H deviates from fx, because carrier H sets a higher transport price, corresponding to a smaller investment of firm H, the exports of firm H decrease ($t_H^{l,fx} > t_H^{fx}$ and $q_{HF}^{l,fx} < q_{HF}^{fx}$). The transport price ($t_H$) increases and the transport demand (i.e., firm H's exports) decreases. As a result, the profit of carrier H does not necessarily become larger than that in the case of fx (see Fig. 5).

Proposition 4. *(i) If $\gamma < \gamma^{**} \simeq 2.32792$, $\tilde{\Pi}_i^s > \tilde{\Pi}_i^l > \tilde{\Pi}_i^{fx}$, and if $\gamma > \gamma^{**}$, $\tilde{\Pi}_i^s > \tilde{\Pi}_i^{fx} > \tilde{\Pi}_i^l$. (ii) $\tilde{\pi}^l > \tilde{\pi}^{fx} > \tilde{\pi}^s$.*

Figs. 8 and 9 illustrate the equilibrium export, R&D investments, and transport prices.

[Figs. 8 and 9 around here]

From Proposition 4, we find the following. When the monopoly carrier can decide on the contract type for the transport price, it always chooses the floating-price contract. On the one hand, if γ is small, the fixed-price contract is the worst scheme for firms. On the other hand, if γ is large, the floating-price contract is the worst scheme for the firms. Hence, because there are two "worst schemes" for the firms, a comparison between a fixed-price contract in both countries and a floating-price contract in both countries is reasonable.

The reason of part (i) of Proposition 4 is as follows. There are two major factors that induce a low profit for firms. The first is a "large investment." When γ is large, the investment efficiency is low. In this case, a large investment sharply increases the investment cost, yielding a lower profit than in the case of a small investment. The second is "aggressive exports." Firms must pay a transport price to export its products. Thus, aggressive exports are less-efficient activities and yield a lower profit. In the simultaneous move scenario, both investments and exports are smallest among all schemes and, therefore, that scheme is best for the firms.

That the profit in the floating-price contract can be the smallest among all schemes is the result of the common transport price set by the monopoly carrier. In a floating-price contract with a firm-specific carrier, firms have an incentive to set a smaller investment to reduce the transport price. In contrast, in the monopoly carrier case, a reduction in the transport price decreases the cost for both firms and, thus, also helps its rival. Therefore, neither firm has an incentive to undertake a smaller investment. As a result, $\tilde{x}_i^l > \tilde{x}_i^{fx}$ holds (see Fig. 9). In the fixed-price contract, the monopoly carrier strategically sets a lower transport price in order to increase the firms' investments, and the exports are largest among all schemes (see Figs. 8 and 9).

If γ is small, because the investment is efficient, the contract scheme that makes the export volume larger yields a lower profit. Thus, the fixed-price contract is the worst scheme for the firms when γ is small. In contrast, if γ is large, because the investment is less-efficient, the contract scheme that makes the investment bigger yields a lower profit. That is, when γ is large, the floating-price contract becomes the worst scheme for the firms.

The reasoning behind part (ii) is as follows. If the carrier is a monopoly, the sum of the two firms' export volumes is the transport demand. Thus, the monopoly carrier has double the demand compared to the case of a firm-specific carrier. This demand expansion means the carrier can gain a bigger surplus by raising its price. In the floating-price contract, the firms' investments are the biggest of the schemes and the monopoly carrier can set a higher price (see Fig. 9). Hence, the floating-price contract maximizes the carrier's profit.

In the fixed-price contract, the carrier strategically commits to reducing its price in order to increase the firms' investments, and so sets a lower transport price. Although this behavior increases exports, it yields the lowest transport price among the schemes (see Figs. 8 and 9). Hence, the carrier's profit is smaller than that in the case of the floating-price contract. In the simultaneous move scenario, the carrier and the firms behave as though each player's strategy is given. Because the carrier cannot adjust a firm's investment through a strategic commitment on its price, the carrier's profit is smaller than that in the case of the fixed-price contract.

4.3 R&D spillovers

Here, we introduce an exogenous spillover rate of R&D, δ, in the previous setting. Since the developed-knowledge of the rival firm is transmitted, firm i's marginal production cost is rewritten as $c - x_i - \delta x_j$ $(i \neq j)$.

We assume that the spillover rate is not very large: $0 \leq \delta < \frac{73-3\sqrt{377}}{44}$ (≈ 0.33529). We exclude the case with a high spillover rate for the following reason. In the previous section, R&D investments are strategic substitutes. However, under a rather high spillover rate, the investment decisions become strategic complements. Hence, under a high spillover rate, we do not have a mechanism in the previous section and we obtain a significantly different profit ranking. We omit the case with a high spillover rate.

Firm i's profit is $\Pi_i(\delta) = [p_i - (c - x_i - \delta x_j)]q_{ii} + [p_j - (c - x_i - \delta x_j) - t_i]q_{ij} - \gamma x_i^2$ and carrier i's profit is $\pi_i(\delta) = t_i q_{ij}$. We consider the same contract schemes and the same timing of the game. The equilibrium outcomes under the fixed-price contract are

$$x_i^{fx}(\delta) = \frac{(a-c)(\delta-2)[-189\gamma^2 + 6\gamma(10\delta^2 - 43\delta + 46) + 20(\delta-2)^2(\delta^2-1)]}{(9\gamma + 2\delta^2 - 2\delta - 4)[108\gamma^2 - 39\gamma(\delta-2)^2 - 10(\delta-2)^2(\delta^2-1)]},$$

$$q_{ii}^{fx}(\delta) = \frac{3\gamma(a-c)[135\gamma^2 - 3\gamma(16\delta^2 - 67\delta + 70) - 16(\delta-2)^2(\delta^2-1)]}{(9\gamma + 2\delta^2 - 2\delta - 4)[108\gamma^2 - 39\gamma(\delta-2)^2 - 10(\delta-2)^2(\delta^2-1)]},$$

$$q_{ij}^{fx}(\delta) = \frac{3\gamma(a-c)[54\gamma^2 - 3\gamma(4\delta^2 - 19\delta + 22) - 4(\delta-2)^2(\delta^2-1)]}{(9\gamma + 2\delta^2 - 2\delta - 4)[108\gamma^2 - 39\gamma(\delta-2)^2 - 10(\delta-2)^2(\delta^2-1)]},$$

$$t_i^{fx}(\delta) = \frac{9\gamma(a-c)(3\gamma - 2\delta^2 + 6\delta - 4)}{108\gamma^2 - 39\gamma(\delta-2)^2 - 10(\delta-2)^2(\delta^2-1)}.$$

The equilibrium outcomes under the floating-price contract are

$$x_i^l(\delta) = \frac{(a-c)(43-14\delta)}{144\gamma + 14\delta^2 - 29\delta - 43}; \quad q_{ii}^l(\delta) = \frac{60\gamma(a-c)}{144\gamma + 14\delta^2 - 29\delta - 43},$$

$$q_{ij}^l(\delta) = \frac{24\gamma(a-c)}{144\gamma + 14\delta^2 - 29\delta - 43}; \quad t_i^l(\delta) = \frac{36\gamma(a-c)}{144\gamma + 14\delta^2 - 29\delta - 43}.$$

The equilibrium outcomes under the simultaneous move scenario are

$$x_i^s(\delta) = \frac{7(a-c)(2-\delta)}{36\gamma + 7(\delta^2 - \delta - 2)}; \quad q_{ii}^s(\delta) = \frac{15\gamma(a-c)}{36\gamma + 7(\delta^2 - \delta - 2)},$$

$$q_{ij}^s(\delta) = \frac{6\gamma(a-c)}{36\gamma + 7(\delta^2 - \delta - 2)}; \quad t_i^s(\delta) = \frac{9\gamma(a-c)}{36\gamma + 7(\delta^2 - \delta - 2)}.$$

The firm's profit and the carrier's profit are $\Pi_i^k(\delta) = [q_{ii}^k(\delta)]^2 + [q_{ij}^k(\delta)]^2 - \gamma[x_i^k(\delta)]^2$ and $\pi_i^k(\delta) = t_i^k(\delta)q_{ij}^k(\delta)$ for $k \in \{fx, l, s\}$.

Under our assumptions, $0 \le \delta < \frac{73-3\sqrt{377}}{44}$ and $\gamma > \frac{4}{3}$, we compare equilibrium profit. By numerical calculation, we have $\Pi_i^l(\delta) > \Pi_i^s(\delta) > \Pi_i^{fx}(\delta)$. Thus, part (i) of Proposition 2 does not change.

We next consider the profit ranking of carrier i. Numerical calculation yields Fig. 10. In the lower left area, we have $\pi_i^s(\delta) > \pi_i^l(\delta) > \pi_i^{fx}(\delta)$; in the other area, we obtain $\pi_i^s(\delta) > \pi_i^{fx}(\delta) > \pi_i^l(\delta)$. Hence, part (ii) of Proposition 2 does not change if the spillover rate is small. On the other hand, a high spillover rate yields only the profit ranking $\pi_i^s(\delta) > \pi_i^{fx}(\delta) > \pi_i^l(\delta)$.

[Fig. 10 around here]

Our results change for the following reason. Under a positive spillover rate, an increase in R&D investment reduces the rival firm's marginal cost. Then, firms have a small incentive to invest. This case is similar to that with inefficient investment technology (i.e., large γ). In other words, the effect of an increase in δ is similar that of an increase in γ. In our model, the investment level plays an important role so we therefore obtain Fig. 10.

4.4 Differentiated products

We consider the effects of product differentiation here. To exclude the effect of market expansion by product differentiation (Singh and Vives, 1984), we employ the Shubik and Levitan (1980)-type utility function:[14] $u_i = a(q_{ii}+q_{ji}) - (1-\beta)(q_{ii}^2+q_{ji}^2) - \frac{\beta}{2}(q_{ii}+q_{ji})^2$, $j \neq i$. $\beta \in [0,1]$ is interpreted as the degree of product differentiation. That is, products are homogeneous at $\beta = 1$ and are independent at $\beta = 0$. Moreover, under this utility function, the aggregate demand in country H or F, $q_{ii} + q_{ji}$, does not depend on the degree of product differentiation. In particular, we have $q_{ii} + q_{ji} = a - (p_{ii} + p_{ji})/2$. Hence, we can exclude the market expansion effect.

Solving the utility maximization problem, we have the inverse demand $p_{ii} = a - (2-\beta)q_{ii} - \beta q_{ji}$ and $p_{ij} = a - (2-\beta)q_{ij} - \beta q_{jj}$. Then, firm i's profit is $\Pi_i(\beta) = [p_{ii} - (c - x_i)]q_{ii} + [p_{ij} - (c - x_i) - t_i]q_{ij} - \gamma x_i^2$ and carrier i's profit is $\pi_i(\beta) = t_i q_{ij}$. We consider the same contract schemes and the same timing of the game. The equilibrium outcomes under the fixed-price contract are

$$x_i^{fx}(\beta) = \frac{(a-c)(2-\beta)\Phi_3}{2\Phi_1\Phi_2}; \quad q_{ii}^{fx}(\beta) = \frac{(a-c)(16-16\beta+3\beta^2)\Phi_4}{4(2-\beta)\Phi_1\Phi_2},$$

$$q_{ij}^{fx}(\beta) = \frac{(a-c)(16-16\beta+3\beta^2)\gamma\Phi_5}{2\Phi_1[9\beta^4\gamma + \beta^3(6-96\gamma) + 8\beta^2(44\gamma-5) + \beta(88-512\gamma) + 64(4\gamma-1)]},$$

$$t_i^{fx}(\beta) = \frac{(a-c)(16-16\beta+3\beta^2)^2\gamma\Phi_6}{4(2-\beta)\Phi_2},$$

where we define Φ_m ($m = 1, \ldots, 6$) as in Appendix C.

The equilibrium outcomes under the floating-price contract are

$$x_i^l(\beta) = \frac{(a-c)(320-448\beta+200\beta^2-29\beta^3)}{\Psi_1}; \quad q_{ii}^l(\beta) = \frac{4(a-c)(8-3\beta)(16-16\beta+3\beta^2)\gamma}{\Psi_1},$$

$$q_{ij}^l(\beta) = \frac{8(a-c)(2-\beta)(16-16\beta+3\beta^2)\gamma}{\Psi_1}; \quad t_i^l(\beta) = \frac{4(a-c)(16-16\beta+3\beta^2)^2\gamma}{\Psi_1},$$

[14] Our qualitative results do not change when using the utility function proposed by Singh and Vives (1984).

where $\Psi_1 \equiv 48\beta^4\gamma + \beta^3(29 - 544\gamma) + 8\beta^2(272\gamma - 25) - 448\beta(8\gamma - 1) + 64(32\gamma - 5)$.

The equilibrium outcomes under the simultaneous move scenario are

$$x_i^s(\beta) = \frac{(a-c)(2-\beta)(12-5\beta)}{\Psi_2}; \quad q_{ii}^s(\beta) = \frac{(a-c)(8-3\beta)(16-16\beta+3\beta^2)\gamma}{2(2-\beta)\Psi_2},$$

$$q_{ij}^s(\beta) = \frac{(a-c)(16-16\beta+3\beta^2)\gamma}{\Psi_2}; \quad t_i^s(\beta) = \frac{(a-c)(4-3\beta)^2(-4+\beta)^2\gamma}{2(2-\beta)\Psi_2},$$

where $\Psi_2 \equiv -6\beta^3\gamma + \beta^2(56\gamma - 5) + \beta(22 - 160\gamma) + 8(16\gamma - 3)$. The firm's profit and the carrier's profit are $\Pi_i^k(\beta) = (2-\beta)\big([q_{ii}^k(\beta)]^2 + [q_{ij}^k(\beta)]^2\big) - \gamma[x_i^k(\beta)]^2$ and $\pi_i^k(\beta) = t_i^k(\beta)q_{ij}^k(\beta)$ for $k \in \{fx, l, s\}$.

Under our assumptions, $0 \leq \beta \leq 1$ and $\gamma > 4/3$, we compare equilibrium profit. By numerical calculation, we depict the profit ranking of firm i in Fig. 11. On the right, we find $\Pi_i^l(\beta) > \Pi_i^s(\beta) > \Pi_i^{fx}(\beta)$; in the middle, we have $\Pi_i^l(\beta) > \Pi_i^{fx}(\beta) > \Pi_i^s(\beta)$; and on the left, we obtain $\Pi_i^{fx}(\beta) > \Pi_i^l(\beta) > \Pi_i^s(\beta)$. That is, in the case with higher product differentiation, the firms with fixed-price contracts earn larger profits.

[Fig. 11 around here]

The reason is as follows. When products are highly differentiated, competitions between firms become less important. Then, the firms' profits depend on vertical relationships between the firms and carriers. Hence, a commitment toward aggressive investment will increase profit in a channel. Therefore, product differentiation brings higher profits to the firms.

Next, we consider the profit ranking of carrier i. Fig. 12 illustrates the numerical calculation. In the lower right area, we have $\pi_i^s(\beta) > \pi_i^l(\beta) > \pi_i^{fx}(\beta)$; in the middle, we find $\pi_i^s(\beta) > \pi_i^{fx}(\beta) > \pi_i^l(\beta)$; and on the left, we obtain $\pi_i^{fx}(\beta) > \pi_i^s(\beta) > \pi_i^l(\beta)$. Hence, under higher product differentiation, carriers prefer fixed-price contracts. The intuition behind this result is similar as in the case of firms.

[Fig. 12 around here]

4.5 Non-linear production costs

To check the robustness of Proposition 2, we introduce non-linear cost terms. For simplicity, we assume that these terms take quadratic forms and that they are not affected by R&D. We consider two cases: (i) adding $\sigma(q_{ii} + q_{ij})^2$ to firm i's cost, and

(ii) adding $\theta(q_{ii}^2 + q_{ij}^2)$ to firm i's cost, where σ and θ are non-negative constants. Case (i) is related to the situation where the production cost depends only on the total output. Case (ii) implies that production plants are different for domestic and foreign sales. In both two cases, if σ and θ are zero, the model reduces to that in the previous section. That is, by considering positive σ and θ, we can discuss the effects of cost non-linearity on the main results. The calculations and a formal expression of the results are provided in Appendix D.

In case (i), we have the same ranking of the firm's profit: $\bar{\Pi}_i^l > \bar{\Pi}_i^s > \bar{\Pi}_i^{fx}$, where the overbar denotes the equilibrium outcomes in case (i). Hence, our result is robust for this type of non-linearity. On the other hand, for large σ, we have a different result for the carrier's profit ranking. We depict the carrier's profit ranking in Fig. 13. In the shaded area, we have $\bar{\pi}_i^s > \bar{\pi}_i^l > \bar{\pi}_i^{fx}$; in the dotted area, we have $\bar{\pi}_i^s > \bar{\pi}_i^{fx} > \bar{\pi}_i^l$; and in the white area, we have $\bar{\pi}_i^{fx} > \bar{\pi}_i^s > \bar{\pi}_i^l$. Hence, we confirm that the main result is robust for small σ only.

[Fig. 13 around here]

Next, we consider case (ii). We depict the firm's profit ranking in Figs. 14–16. In the shaded or dotted areas, the firm's profit with the floating-price contract is larger than that with the fixed-price contract. On the other hand, the white area shows the reverse relationship. Hence, our main result is robust for small θ.

[Figs. 14–16 around here]

[Fig. 17 around here]

We depict the carrier's profit ranking in Fig. 17. For small θ, the main result is robust. That is, the carrier's profit in the floating-price contract is larger than that in the fixed-price contract if γ is small; the reverse relationship is true if γ takes a large value. Moreover, under small θ, the fixed-price contract is not the best contract option for carriers. However, for large θ, the fixed-price contract becomes the best option for carriers. This point differs from the main result.

Summing up the results in cases (i) and (ii), as the non-linearity of the cost become more effective, we find that the fixed-price contract yields larger profits to the firms and to the carriers. The logic behind this result is simple. For large σ or θ, the marginal costs of the firms increase rapidly. Thus, cost-reducing R&D plays a more important role. We know that the fixed-price contract leads to a large investment in order to reduce costs. Hence, the fixed-price contract provides the largest profits for the firms and the carriers.

5 Conclusion

In a vertical production relationship, upstream trading firms likely hold up downstream R&D investment. If these upstream firms set a higher input price after observing downstream investment, then they can extract the downstream R&D benefit, and such opportunistic behavior reduces downstream innovation incentives. The previous literature emphasizes that a fixed-price contract for the input price is required to overcome this hold-up problem. In the fixed-price contract, upstream firms commit to an input price level and downstream firms subsequently invest in cost-reducing R&D. By employing the fixed-price contract, upstream firms set a lower input price to promote downstream investment. Since this lower-price commitment increases outputs and demand for inputs through investment expansion, all firms become better off.

In contrast to this standard theory, we show that the fixed-price contract can harm all firms. We consider a two-country, two-way trade model with two firm-specific carriers upstream, and two exporters downstream. Each country has a carrier and an exporting firm. While each country's exporting firm freely supplies to the domestic market, it uses a local carrier to export its product. Each carrier charges a transport price and conveys its domestic exporting firm's product. In this setting, exporters can create a situation close to a domestic monopoly when the transport price is high enough. Although the domestic monopoly is most profitable for exporters, the fixed-price contract lowers the transport price and encourages firms to invest and export aggressively, creating a market furthest from a domestic monopoly. This makes exporters worse off. Furthermore, if R&D efficiency is high enough, carriers set considerably low transport prices in the fixed-price contract. This also makes carriers worse off. We also examined asymmetric contract schemes between two countries and the monopoly carrier case. Moreover, we examined the robustness of the main result in three situations: positive R&D spillovers; product differentiation; and non-linear production costs. We find that our main result holds in these extended cases.

This study shows that a fixed-price transportation contract can harm all firms in both upstream and downstream markets when downstream firms engage in cost-reducing R&D. Therefore, it would be interesting to investigate other forms of R&D, such as product innovation and product quality improvement to determine whether our result holds. However, this issue is beyond the scope of our study, and we thus leave it to future research.

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Appendix A. Proofs

Proof of Proposition 1. (i) $x_i^{fx} - x_i^s = \frac{9\gamma(15\gamma-8)(a-c)}{2(3\gamma-1)(9\gamma-10)(9\gamma-4)(18\gamma-7)} > 0$ and $x_i^s - x_i^l = \frac{234\gamma(a-c)}{(18\gamma-7)(144\gamma-43)} > 0$. (ii) Differentiating (3), (7), and (12) w.r.t. γ, we obtain $\partial x_i^{fx}/\partial\gamma = -\frac{27(1701\gamma^4-4968\gamma^3+5130\gamma^2-2160\gamma+320)(a-c)}{2(9\gamma-4)^2(9\gamma-10)^2(3\gamma-1)^2} < 0$, $\partial x_i^l/\partial\gamma = -\frac{6192(a-c)}{(144\gamma-43)^2} < 0$, and $\partial x_i^s/\partial\gamma = -\frac{126(a-c)}{(18\gamma-7)^2} < 0$. Q.E.D.

Proof of Lemma 1. (i) $t_i^s - t_i^l = \frac{117\gamma(a-c)}{2(18\gamma-7)(144\gamma-43)} > 0$ and $t_i^l - t_i^{fx} = \frac{27\gamma(27\gamma-4)(a-c)}{4(3\gamma-1)(9\gamma-10)(144\gamma-43)} > 0$. (ii) Differentiating (2), (8), and (11) w.r.t. γ, we have $\partial t_i^s/\partial\gamma = \frac{-1548(a-c)}{(144\gamma-43)^2} < 0$; $\partial t_i^l/\partial\gamma = \frac{-63(a-c)}{2(18\gamma-7)^2} < 0$; $\partial t_i^{fx}/\partial\gamma = \frac{-9(9\gamma^2-60\gamma+40)(a-c)}{4(9\gamma-10)^2(3\gamma-1)^2}$. From the last equation, $\partial t_i^{fx}/\partial\gamma < (\geq)\ 0$ if $\gamma > (\leq)\ \frac{2(\sqrt{15}+5)}{3} \simeq 5.91532$. Q.E.D.

Proof of Lemma 2. I. Comparing exports, we get $q_{ij}^{fx} - q_{ij}^s = \frac{9\gamma(15\gamma-8)(a-c)}{2(9\gamma-10)(9\gamma-4)(18\gamma-7)} > 0$ and $q_{ij}^s - q_{ij}^l = \frac{39\gamma(a-c)}{(18\gamma-7)(144\gamma-43)} > 0$. Comparing domestic supplies, we have $q_{ii}^s - q_{ii}^l = \frac{195\gamma(a-c)}{2(18\gamma-7)(144\gamma-43)} > 0$, $q_{ii}^s - q_{ii}^{fx} = \frac{9\gamma(3\gamma-2)(15\gamma-8)(a-c)}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)(18\gamma-7)} > 0$, and $q_{ii}^{fx} - q_{ii}^l = \frac{3\gamma(675\gamma^2-1434\gamma+448)(a-c)}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)(144\gamma-43)}$. From $q_{ii}^{fx} - q_{ii}^l$, solving $675\gamma^2 - 1434\gamma + 448 \geq 0$ w.r.t. γ, we have $q_{ii}^{fx} < (\geq)\ q_{ii}^l$ if $\gamma < (\geq)\ \frac{\sqrt{23521}+239}{225} \simeq 1.74385$. Comparing total sales, we have $Q_i^{fx} - Q_i^s = \frac{27(a-c)\gamma^2(15\gamma-8)}{4(3\gamma-1)(9\gamma-10)(9\gamma-4)(18\gamma-7)} > 0$ and $Q_i^s - Q_i^l = \frac{273(a-c)\gamma}{2(18\gamma-7)(144\gamma-43)} > 0$.
II. From (4), (9), and (13), we get $\partial q_{ij}^l/\partial\gamma = -1032(a-c)/(144\gamma-43)^2 < 0$, $\partial q_{ij}^s/\partial\gamma = -21(a-c)/(18\gamma-7)^2 < 0$, $\partial q_{ij}^{fx}/\partial\gamma = \frac{-3(243\gamma^2-360\gamma+160)(a-c)}{(9\gamma-4)^2(9\gamma-10)^2} < 0$, $\partial q_{ii}^l/\partial\gamma = -2580(a-$

$c)/(144\gamma-43)^2 < 0$, $\partial q_{ii}^s/\partial\gamma = -105(a-c)/[2(18\gamma-7)^2] < 0$, and $\partial q_{ii}^{fx}/\partial\gamma = \frac{-3(10935\gamma^4-35316\gamma^3+38484\gamma^2-16800\gamma+2560)(a-c)}{4(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2}$. From the last equation, $\partial q_{ii}^{fx}/\partial\gamma > (\leq) 0$ if $\gamma < (\geq)\ \hat{\gamma} \simeq 1.48449$. For the total sales, the derivation yields $\partial Q_i^s/\partial\gamma = -147(a-c)/[2(18\gamma-7)^2] < 0$, $\partial Q_i^l/\partial\gamma = -3612(a-c)/(144\gamma-43)^2 < 0$, and $\partial Q_i^{fx}/\partial\gamma = \frac{-3(a-c)(3200-22080\gamma+53856\gamma^2-54108\gamma^3+19683\gamma^4)}{4(9\gamma-4)^2(9\gamma^2-10)^2(3\gamma-1)^2} < 0$. Q.E.D.

Proof of Proposition 2. (i) $\Pi_i^l - \Pi_i^s = \frac{117\gamma^2(5904\gamma-1945)(a-c)^2}{4(18\gamma-7)^2(144\gamma-43)^2} > 0$ and $\Pi_i^s - \Pi_i^{fx} = \frac{9\gamma^2(15\gamma-8)(8748\gamma^4-12879\gamma^3-864\gamma^2+4440\gamma-1024)(a-c)^2}{16(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2(18\gamma-7)^2} > 0$.

(ii) $\pi_i^s - \pi_i^l = \frac{3159\gamma^2(32\gamma-11)(a-c)^2}{2(18\gamma-7)^2(144\gamma-43)^2} > 0$, $\pi_i^s - \pi_i^{fx} = \frac{27\gamma^2(15\gamma-8)(27\gamma-4)(a-c)^2}{8(3\gamma-1)(9\gamma-10)^2(9\gamma-4)(18\gamma-7)^2} > 0$, and $\pi_i^{fx} - \pi_i^l = \frac{27\gamma^2(101088\gamma^3-285309\gamma^2+214692\gamma-43232)(a-c)^2}{8(3\gamma-1)(9\gamma-10)^2(9\gamma-4)(144\gamma-43)^2}$. From the last equation, $\pi_i^{fx} - \pi_i^l \leq (>)\ 0$ if $\gamma \leq (>)\ \gamma^* \simeq 1.74661$. Q.E.D.

Proof of Proposition 3. (i) From Lemma 2, $CS^{fx} > CS_i^s > CS_i^l$. $W_i^{fx} - W_i^s = \frac{9\gamma^2(15\gamma-8)(4860\gamma^3-8667\gamma^2+4056\gamma-560)(a-c)^2}{32(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)(18\gamma-7)^2} > 0$ and $W_i^s - W_i^l = \frac{117\gamma^2(5760\gamma-2149)(a-c)^2}{8(18\gamma-7)^2(144\gamma-43)^2} > 0$.

(ii) Differentiating eqs. (15) and (16) w.r.t. γ, we get

$$\frac{\partial CS_i^{fx}}{\partial\gamma} = -\frac{9\gamma(189\gamma^2-276\gamma+80)(19683\gamma^4-54108\gamma^3+53856\gamma^2-22080\gamma+3200)(a-c)^2}{16(3\gamma-1)^3(9\gamma-10)^3(9\gamma-4)^3} < 0,$$

$$\frac{\partial CS_i^l}{\partial\gamma} = -\frac{303408\gamma(a-c)^2}{(144\gamma-43)^3} < 0, \quad \frac{\partial CS_i^s}{\partial\gamma} = -\frac{3087\gamma(a-c)^2}{4(18\gamma-7)^3} < 0,$$

$$\frac{\partial W_i^{fx}}{\partial\gamma} = -\frac{\begin{bmatrix} 4586139\gamma^6-19503666\gamma^5+33045084\gamma^4-28257120\gamma^3 \\ +12744000\gamma^2-2880000\gamma+256000 \end{bmatrix}(a-c)^2}{16(9\gamma-4)^2(3\gamma-1)^3(9\gamma-10)^3} < 0,$$

$$\frac{\partial W_i^l}{\partial\gamma} = -\frac{43(10944\gamma-1849)(a-c)^2}{(144\gamma-43)^3} < 0, \text{ and } \frac{\partial W_i^s}{\partial\gamma} = -\frac{49(81\gamma-28)(a-c)^2}{4(18\gamma-7)^3} < 0.$$

Q.E.D.

Proof of Proposition 4. (i) $\tilde{\Pi}_i^s - \tilde{\Pi}_i^{fx} = \frac{3\gamma^2(972\gamma^3+189\gamma^2-576\gamma+136)(a-c)^2}{16(3\gamma-1)^2(9\gamma-4)^2(18\gamma-7)^2} > 0$, $\tilde{\Pi}_i^s - \tilde{\Pi}_i^l = \frac{9\gamma^2(15696\gamma-6131)(a-c)^2}{4(18\gamma-7)^2(288\gamma-113)^2} > 0$, and $\tilde{\Pi}_i^l - \tilde{\Pi}_i^{fx} = \frac{3(a-c)^2\gamma^2(59464-338688\gamma+541809\gamma^2-174960\gamma^3)}{16(3\gamma-1)^2(9\gamma-4)^2(288\gamma-113)^2}$. From the last equation, $\tilde{\Pi}_i^l - \tilde{\Pi}_i^{fx} \geq (<)\ 0$ if $\gamma \leq (>)\ \gamma^{**} \simeq 2.32792$.

(ii) $\tilde{\pi}_i^l - \tilde{\pi}_i^{fx} = \frac{9\gamma^2(576\gamma-481)(a-c)^2}{4(3\gamma-1)(9\gamma-4)(288\gamma-113)^2} > 0$ and $\tilde{\pi}_i^{fx} - \tilde{\pi}_i^s = \frac{9\gamma^2(a-c)^2}{4(3\gamma-1)(9\gamma-4)(18\gamma-7)^2} > 0$.

Q.E.D.

Appendix B. The outcomes in asymmetric contract schemes

The domestic supply is $q_{HH}^{fx,l} = q_{FF}^{l,fx} = \frac{3\gamma(1620\gamma^3-3474\gamma^2+2256\gamma-445)(a-c)}{4(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$ and $q_{FF}^{fx,l} = q_{HH}^{l,fx} = \frac{3\gamma(3240\gamma^3-7416\gamma^2+5304\gamma-1145)(a-c)}{8(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$.

The exports are $q_{HF}^{fx,l} = q_{FH}^{l,fx} = \frac{9\gamma(216\gamma^3-408\gamma^2+216\gamma-35)(a-c)}{4(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$ and $q_{FH}^{fx,l} = q_{HF}^{l,fx} = \frac{3\gamma(324\gamma^3-738\gamma^2+528\gamma-115)(a-c)}{2(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$.
The transport price is $t_H^{fx,l} = t_F^{l,fx} = \frac{81\gamma(6\gamma-5)(12\gamma^2-18\gamma+5)(a-c)}{8(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$ and $t_F^{fx,l} = t_H^{l,fx} = \frac{9\gamma(6\gamma-5)(54\gamma^2-78\gamma+23)(a-c)}{4(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$.
The R&D investment is $x_H^{fx,l} = x_F^{l,fx} = \frac{(1134\gamma^3-2349\gamma^2+1452\gamma-275)(a-c)}{2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275}$ and $x_F^{fx,l} = x_H^{l,fx} = \frac{(1944\gamma^3-4122\gamma^2+2709\gamma-550)(a-c)}{2(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}$.
The carrier's profit is $\pi_H^{fx,l} = \pi_F^{l,fx} = \frac{729\gamma^2(12\gamma^2-18\gamma+5)^2(108\gamma^2-132\gamma+35)(a-c)^2}{32(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2}$ and $\pi_F^{fx,l} = \pi_H^{l,fx} = \frac{27(6\gamma-5)^2\gamma^2(54\gamma^2-78\gamma+23)^2(a-c)^2}{8(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2}$.
The firm's profit is

$$\Pi_H^{fx,l} = \frac{\gamma\begin{bmatrix} 13699368\gamma^7-68076936\gamma^6+140342706\gamma^5-155262420\gamma^4 \\ +99424098\gamma^3-36849672\gamma^2+7329525\gamma-605000 \end{bmatrix}(a-c)^2}{8(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2},$$

$$\Pi_F^{fx,l} = \frac{\gamma\begin{bmatrix} 109594944\gamma^7-561831552\gamma^6+1188421632\gamma^5-1338126480\gamma^4 \\ +862165296\gamma^3-316768896\gamma^2+61382025\gamma-4840000 \end{bmatrix}(a-c)^2}{64(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2},$$

where $\Pi_H^{fx,l} = \Pi_F^{l,fx}$ and $\Pi_F^{fx,l} = \Pi_H^{l,fx}$.
Derivation of multiple equilibria. From (5), (10), $\Pi_H^{fx,l}$ $(= \Pi_F^{l,fx})$, and $\Pi_F^{fx,l}$ $(= \Pi_H^{l,fx})$, we have

$$\Pi_i^l - \Pi_H^{fx,l} = \frac{3\gamma^2(a-c)^2}{8(144\gamma-43)^2(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2} \times \Delta_1 > 0,$$
$$\Pi_i^{fx} - \Pi_H^{l,fx} = \frac{3\gamma^2(a-c)^2}{64(3\gamma-1)^2(9\gamma-10)^2(9\gamma-4)^2(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)^2} \times \Delta_2 > 0,$$

where $\Delta_1 \equiv 1201765248\gamma^7-3051809784\gamma^6+1210040856\gamma^5+3155333130\gamma^4-4170870684\gamma^3+2097188154\gamma^2-485344920\gamma+42887825 > 0$ and $\Delta_2 \equiv 49589822592\gamma^{11}-308099731104\gamma^{10}+790452588816\gamma^9-1034271342324\gamma^8+609048392112\gamma^7+125643515229\gamma^6-489041480826\gamma^5+383268523365\gamma^4-160976987172\gamma^3+39371526756\gamma^2-5285282400\gamma+301640000 > 0$.

Hence, there is no incentive for firms H and F to deviate from l and fx. When in the first stage of the game, two firms can choose between two types of contract (i.e., a floating-price or a fixed-price contract), only the multiple equilibria (fx and l) appear.
Reduction in outputs. The deviation from fx reduces the total output (the sum of domestic supply and exports) of the deviating firm. The above outcomes in the asym-

metric contract schemes and (4) yield

$$(q_{HH}^{fx}+q_{HF}^{fx})-(q_{HH}^{l,fx}+q_{HF}^{l,fx})=\frac{3\gamma(3\gamma-2)(58320\gamma^4-171234\gamma^3+174321\gamma^2-71325\gamma+10100)(a-c)}{8(3\gamma-1)(9\gamma-10)(9\gamma-4)(2916\gamma^4-7452\gamma^3+6525\gamma^2-2292\gamma+275)}>0.$$

Appendix C. Definition of Φ_m

We define Φ_m ($m=1,\dots,6$) as follows: $\Phi_1\equiv 3\beta^3\gamma+\beta^2(4-28\gamma)+16\beta(5\gamma-1)-64\gamma+16$, $\Phi_2\equiv 27\beta^6\gamma^2+27\beta^5(1-16\gamma)\gamma+6\beta^4(1-55\gamma+456\gamma^2)-4\beta^3(13-386\gamma+2176\gamma^2)+24\beta^2(7-144\gamma+608\gamma^2)-16\beta(15-232\gamma+768\gamma^2)+128(1-12\gamma+32\gamma^2)$, $\Phi_3\equiv 135\beta^7\gamma^2-36\beta^6\gamma(69\gamma-5)+48\beta^5(1-53\gamma+393\gamma^2)-16\beta^4(32-909\gamma+4772\gamma^2)+128\beta^3(17-337\gamma+1386\gamma^2)-512\beta^2(9-137\gamma+462\gamma^2)+256\beta(19-232\gamma+656\gamma^2)-2048(1-10\gamma+24\gamma^2)$, $\Phi_4\equiv 81\beta^7\gamma^2-6\beta^6\gamma(252\gamma-19)+8\beta^5(4-205\gamma+1458\gamma^2)-8\beta^4(44-1193\gamma+6000\gamma^2)+128\beta^3(12-225\gamma+886\gamma^2)-256\beta^2(13-186\gamma+600\gamma^2)+512\beta(7-80\gamma+216\gamma^2)-512(3-28\gamma+64\gamma^2)$, $\Phi_5\equiv -9\beta^4\gamma-\beta^3(8-96\gamma)-16\beta^2(22\gamma-3)-\beta(96-512\gamma)-64(4\gamma-1)$, and $\Phi_6\equiv -9\beta^3\gamma-\beta^2(4-60\gamma)-16\beta(7\gamma-1)+64\gamma-16$.

Appendix D. Non-linear production costs

Throughout this section, we assume $\gamma>\frac{4}{3}$.

• *Case (i).* Incorporating $\sigma(q_{ii}+q_{ij})^2$ into the cost function of firm i, the profit of firm i is $\bar{\Pi}_i\equiv[p_i-(c-x_i)]q_{ii}+[p_j-(c-x_i)-t_i]q_{ij}-\sigma(q_{ii}+q_{ij})^2-\gamma x_i^2$. Because the settings other than the firm's cost are much the same, we obtain the following equilibrium outcomes in a similar way to that described in Section 3.

For the fixed-price contract, we have

$$\bar{q}_{ii}^{fx}=\frac{\lambda}{4\Lambda_1^{fx}\Lambda_2^{fx}\Lambda_3^{fx}}\left[\begin{array}{l}\gamma^2(4\sigma+1)^2(4\sigma+3)^2(64\sigma^2+70\sigma+15)\\ -2\gamma(4\sigma+1)(4\sigma+3)(64\sigma+35)(2\sigma+1)^2+64(2\sigma+1)^4\end{array}\right],$$

$$\bar{q}_{ij}^{fx}=\frac{\lambda}{2\Lambda_2^{fx}\Lambda_3^{fx}}[\gamma(4\sigma+1)(4\sigma+3)(8\sigma+3)-8(2\sigma+1)^2],$$

$$\bar{t}_i^{fx}=\frac{3\lambda}{4\Lambda_1^{fx}\Lambda_3^{fx}}[\gamma(4\sigma+1)^2(4\sigma+3)-4(2\sigma+1)^2],$$

$$\bar{x}_i^{fx}=\frac{(a-c)(1+2\sigma)^2}{2\Lambda_1^{fx}\Lambda_2^{fx}\Lambda_3^{fx}}\left[\begin{array}{l}\gamma^2(4\sigma+1)^2(4\sigma+3)^2(80\sigma^2+92\sigma+21)\\ -4\gamma(4\sigma+1)(4\sigma+3)(40\sigma+23)(2\sigma+1)^2+80(2\sigma+1)^4\end{array}\right],$$

where $\lambda\equiv(a-c)\gamma(4\sigma+1)(4\sigma+3)$, $\Lambda_1^{fx}\equiv\gamma(\sigma+1)(4\sigma+1)(4\sigma+3)-(2\sigma+1)^2$, $\Lambda_2^{fx}\equiv\gamma(4\sigma+1)(4\sigma+3)^2-4(2\sigma+1)^2$, and $\Lambda_3^{fx}\equiv\gamma(4\sigma+1)(4\sigma+3)(10\sigma+3)-10(2\sigma+1)^2$.

Then, the equilibrium profits of firm i and carrier i are $\bar{\Pi}_i^{fx} = [a - \bar{q}_{ii}^{fx} - \bar{q}_{ji}^{fx} - (c - \bar{x}_i^{fx})]\bar{q}_{ii}^{fx} + [a - \bar{q}_{jj}^{fx} - \bar{q}_{ij}^{fx} - (c - \bar{x}_i^{fx}) - \bar{t}_i^{fx}]\bar{q}_{ij}^{fx} - \sigma(\bar{q}_{ii}^{fx} + \bar{q}_{ij}^{fx})^2 - \gamma(\bar{x}_i^{fx})^2$ and $\bar{\pi}_i^{fx} = \bar{t}_i^{fx}\bar{q}_{ij}^{fx}$, respectively.

For the floating-price contract, we have

$$\begin{aligned}
\bar{q}_{ii}^{l} &= \frac{4\lambda}{\Lambda^l}(1280\sigma^4 + 2424\sigma^3 + 1612\sigma^2 + 450\sigma + 45),\\
\bar{q}_{ij}^{l} &= \frac{8\lambda}{\Lambda^l}(160\sigma^4 + 348\sigma^3 + 260\sigma^2 + 81\sigma + 9),\\
\bar{t}_i^{l} &= \frac{12(a-c)}{\Lambda^l}\gamma(2\sigma+1)(10\sigma+3)(16\sigma^2+16\sigma+3)^2,\\
\bar{x}_i^{l} &= \frac{(a-c)}{\Lambda^l}(51200\sigma^6 + 147968\sigma^5 + 172160\sigma^4 + 103168\sigma^3 + 33616\sigma^2 + 5664\sigma + 387),
\end{aligned}$$

where $\Lambda^l \equiv 16\gamma(40\sigma^2+42\sigma+9)^2(8\sigma^3+14\sigma^2+7\sigma+1) - 51200\sigma^6 - 147968\sigma^5 - 172160\sigma^4 - 103168\sigma^3 - 33616\sigma^2 - 5664\sigma - 387$. Then, substituting the outcome into the profits of firm i and carrier i, we obtain the following equilibrium profits: $\bar{\Pi}_i^l$ and $\bar{\pi}_i^l$, respectively.

For the simultaneous move scenario, we have

$$\begin{aligned}
\bar{q}_{ii}^{s} &= \frac{\lambda}{2\Lambda^s}(64\sigma^2+70\sigma+15); \quad \bar{q}_{ij}^{s} = \frac{\lambda}{\Lambda^s}(8\sigma^2+11\sigma+3),\\
\bar{t}_i^{s} &= \frac{3\lambda}{2\Lambda^s}(4\sigma+1)(4\sigma+3); \quad \bar{x}_i^{s} = \frac{(a-c)}{\Lambda^s}(2\sigma+1)^2(80\sigma^2+92\sigma+21),
\end{aligned}$$

where $\Lambda^s \equiv 2\gamma(\sigma+1)(4\sigma+1)(4\sigma+3)^2(10\sigma+3) - (2\sigma+1)^2(80\sigma^2+92\sigma+21)$. Then, substituting the outcome into the profits of firm i and carrier i, we obtain the following equilibrium profits: $\bar{\Pi}_i^s$ and $\bar{\pi}_i^s$, respectively.

Comparing firm i's profit in each case, we establish the following proposition.

Proposition 5. *For any $\sigma \geq 0$, $\bar{\Pi}_i^l > \bar{\Pi}_i^s > \bar{\Pi}_i^{fx}$.*

Proof. First, we show $\bar{\Pi}_i^l > \bar{\Pi}_i^s$. The sign of $\bar{\Pi}_i^l - \bar{\Pi}_i^s$ depends on the sign of $v_1(\sigma)\gamma - v_2(\sigma)$, where $v_1(\sigma) \equiv 16(4\sigma+3)^3(10\sigma+3)^2(19456\sigma^6 + 56832\sigma^5 + 65216\sigma^4 + 37920\sigma^3 + 11860\sigma^2 + 1903\sigma + 123)$ and $v_2(\sigma) \equiv 498073600\sigma^{10} + 2408841216\sigma^9 + 5149294592\sigma^8 + 6405816320\sigma^7 + 5135470592\sigma^6 + 2772634624\sigma^5 + 1021286656\sigma^4 + 253561344\sigma^3 + 40638240\sigma^2 + 3799764\sigma + 157545$. Because $v_1(\sigma)$ and $v_2(\sigma)$ take positive values for any $\sigma \geq 0$ and $\gamma > 4/3$ holds, we have $v_1(\sigma)\gamma - v_2(\sigma) > 4v_1(\sigma)/3 - v_2(\sigma)$. We can easily show that $4v_1(\sigma)/3 - v_2(\sigma) > 0$. Therefore, $\bar{\Pi}_i^l > \bar{\Pi}_i^s$.

Next, we show that $\bar{\Pi}_i^s > \bar{\Pi}_i^{fx}$. The sign of $\bar{\Pi}_i^s - \bar{\Pi}_i^{fx}$ is equal to that of $[y_1(\sigma)\gamma - y_0(\sigma)]\sum_{r=0}^{16} z_r(\gamma)\sigma^r$, where $y_0(\sigma) \equiv 8(2\sigma+1)^3$ and $y_1(\sigma) \equiv (256\sigma^4 + 512\sigma^3 + 384\sigma^2 +$

$128\sigma + 15)$; $z_0(\gamma) \equiv 9(11664\gamma^3 - 12879\gamma^2 - 576\gamma + 1480)$, $z_1(\gamma) \equiv 27(155520\gamma^3 - 165537\gamma^2 + 13024\gamma + 9024)$, $z_2(\gamma) \equiv 16(4797549\gamma^3 - 4851252\gamma^2 + 733248\gamma + 99926)$, $z_3(\gamma) \equiv 4(212659992\gamma^3 - 201825675\gamma^2 + 38462592\gamma + 444832)$, $z_4(\gamma) \equiv 32(199742112\gamma^3 - 176055147\gamma^2 + 36670816\gamma - 1244260)$, $z_5(\gamma) \equiv 64(539282232\gamma^3 - 437231673\gamma^2 + 92542472\gamma - 4814512)$, $z_6(\gamma) \equiv 512(270509940\gamma^3 - 199858809\gamma^2 + 41068456\gamma - 2378035)$, $z_7(\gamma) \equiv 6144(68573952\gamma^3 - 45713250\gamma^2 + 8820226\gamma - 507209)$, $z_8(\gamma) \equiv 8192(119889508\gamma^3 - 71296587\gamma^2 + 12554070\gamma - 672212)$, $z_9(\gamma) \equiv 16384(107496432\gamma^3 - 56230476\gamma^2 + 8782944\gamma - 416225)$, $z_{10}(\gamma) \equiv 131072(18489392\gamma^3 - 8350659\gamma^2 + 1119704\gamma - 44523)$, $z_{11}(\gamma) \equiv 262144(9667480\gamma^3 - 3673305\gamma^2 + 404860\gamma - 12573)$, $z_{12}(\gamma) \equiv 4194304(471252\gamma^3 - 144939\gamma^2 + 12295\gamma - 264)$, $z_{13}(\gamma) \equiv 4194304(265304\gamma^3 - 62055\gamma^2 + 3600\gamma - 40)$, $z_{14}(\gamma) \equiv 134217728\gamma(3181\gamma^2 - 504\gamma + 15)$, $z_{15}(\gamma) \equiv 1610612736\gamma^2(62\gamma - 5)$, and $z_{16}(\gamma) \equiv 10737418240\gamma^3$.

Because $y_1(\sigma)$ is positive and $\gamma > 4/3$, $y_1(\sigma)\gamma - y_0(\sigma)$ must be larger than $4y_1(\sigma)/3 - y_0(\sigma)$. Moreover, we can show that $4y_1(\sigma)/3 - y_0(\sigma) > 0$. Hence, we have $y_1(\sigma)\gamma - y_0(\sigma) > 0$. Here, we show $\sum_{r=0}^{16} z_r(\gamma)\sigma^r > 0$. Because we assume $\gamma > 4/3$, the first derivative of $z_r(\gamma)$ with respect to γ takes a positive value for any $r = 0, 1, \ldots, 16$. Hence, $\sum_{r=0}^{16} z_r(\gamma)\sigma^r > 0$ because $\sigma \geq 0$. Therefore, $[y_1(\sigma)\gamma - y_0(\sigma)] \sum_{r=0}^{16} z_r(\gamma)\sigma^r > 0$, which leads to $\bar{\Pi}_i^s > \bar{\Pi}_i^{fx}$. Q.E.D.

Next, we compare the profits of carrier i in each case. Using a numerical calculation, we obtain the following result.

Result 1. *If γ and σ take small positive values, $\bar{\pi}_i^s > \bar{\pi}_i^l > \bar{\pi}_i^{fx}$; if γ and σ take intermediate values, $\bar{\pi}_i^s > \bar{\pi}_i^{fx} > \bar{\pi}_i^l$; and if γ and σ take large values, $\bar{\pi}_i^{fx} > \bar{\pi}_i^s > \bar{\pi}_i^l$.*

• *Case (ii).* Incorporating $\theta(q_{ii}^2 + q_{ij}^2)$ into the cost function, the profit of firm i is $\hat{\Pi}_i \equiv [p_i - (c - x_i)]q_{ii} + [p_j - (c - x_i) - t_i]q_{ij} - \theta(q_{ii}^2 + q_{ij}^2) - \gamma x_i^2$.

A similar calculation in the case (i) yields the following equilibrium outcomes.

For the fixed-price contract, we have

$$\hat{q}_{ii}^{fx} = \frac{(a-c)\gamma\omega}{4\Omega_1^{fx}\Omega_2^{fx}\Omega_3^{fx}}\left[\begin{array}{l}\gamma^2(4\theta+5)(4\theta^2+8\theta+3)^3+16(3\theta+4)(\theta+1)^4\\ -2\gamma(112\theta^4+480\theta^3+736\theta^2+472\theta+105)(\theta+1)^2\end{array}\right],$$

$$\hat{q}_{ij}^{fx} = \frac{(a-c)\gamma\omega}{2\Omega_1^{fx}\Omega_3^{fx}}[\gamma(4\theta^2+8\theta+3)^2-8(\theta+1)^3],$$

$$\hat{t}_i^{fx} = \frac{(a-c)\gamma\omega^2}{4(1+\theta)\Omega_2^{fx}\Omega_3^{fx}}[\gamma(2\theta+1)^2(2\theta+3)-4(\theta+1)^2],$$

$$\hat{x}_i^{fx} = \frac{(a-c)(1+\theta)}{2\Omega_1^{fx}\Omega_2^{fx}\Omega_3^{fx}}\left[\begin{array}{l}\gamma^2(6\theta+7)(4\theta^2+8\theta+3)^3+16(4\theta+5)(\theta+1)^4\\ -4\gamma(80\theta^4+336\theta^3+504\theta^2+316\theta+69)(\theta+1)^2\end{array}\right],$$

where $\omega \equiv 4\theta^2+8\theta+3$, $\Omega_1^{fx} \equiv \gamma(2\theta+1)(2\theta+3)^2-4(\theta+1)^2$, $\Omega_2^{fx} \equiv \gamma(4\theta^2+8\theta+3)-\theta-1$, and $\Omega_3^{fx} \equiv \gamma(4\theta^2+8\theta+3)^2-2(\theta+1)^2(4\theta+5)$. Then, the equilibrium profits of firm i and carrier i are $\hat{\Pi}_i^{fx} = [a-\hat{q}_{ii}^{fx}-\hat{q}_{ji}^{fx}-(c-\hat{x}_i^{fx})]\hat{q}_{ii}^{fx}+[a-\hat{q}_{jj}^{fx}-\hat{q}_{ij}^{fx}-(c-\hat{x}_i^{fx})-\hat{t}_i^{fx}]\hat{q}_{ij}^{fx}-\theta[(\hat{q}_{ii}^{fx})^2+(\hat{q}_{ij}^{fx})^2]-\gamma(\hat{x}_i^{fx})^2$ and $\hat{\pi}_i^{fx} = \hat{t}_i^{fx}\hat{q}_{ij}^{fx}$, respectively.

For the floating-price contract, we have

$$\hat{q}_{ii}^l = \frac{4(a-c)\gamma(5+4\theta)\omega}{\Omega^l};\quad \hat{q}_{ij}^l = \frac{8(a-c)\gamma(1+\theta)\omega}{\Omega^l},$$

$$\hat{t}_i^l = \frac{4(a-c)\gamma\omega^2}{\Omega^l};\quad \hat{x}_i^l = \frac{(a-c)(40\theta^3+128\theta^2+132\theta+43)}{\Omega^l},$$

where $\Omega^l \equiv 16\gamma(2\theta+3)^2(2\theta^2+3\theta+1)-40\theta^3-128\theta^2-132\theta-43$. Then, substituting the outcome into the profits of firm i and carrier i, we obtain the following equilibrium profits: $\hat{\Pi}_i^l$ and $\hat{\pi}_i^l$, respectively.

For the simultaneous move scenario, we have

$$\hat{q}_{ii}^s=\frac{(a-c)\gamma(5+4\theta)\omega}{2(1+\theta)\Omega^s};\quad \hat{q}_{ij}^s=\frac{(a-c)\gamma\omega}{\Omega^s};\quad \hat{t}_i^s=\frac{(a-c)\gamma\omega^2}{2(1+\theta)\Omega^s};\quad \hat{x}_i^s=\frac{(a-c)(1+\theta)(7+6\theta)}{\Omega^s},$$

where $\Omega^s \equiv 2\gamma(2\theta+1)(2\theta+3)^2-(\theta+1)(6\theta+7)$. Then, substituting the outcome into the profits of firm i and carrier i, we obtain the following equilibrium profits: $\hat{\Pi}_i^s$ and $\hat{\pi}_i^s$, respectively.

Using a numerical calculation, we obtain the following result.

Result 2. *If γ and θ take small positive values, $\hat{\Pi}_i^l > \hat{\Pi}_i^s > \hat{\Pi}_i^{fx}$; if γ and θ take intermediate values, $\hat{\Pi}_i^l > \hat{\Pi}_i^{fx} > \hat{\Pi}_i^s$; and if γ and θ take large values, $\hat{\Pi}_i^{fx} > \hat{\Pi}_i^l > \hat{\Pi}_i^s$.*

Result 3. *If γ and θ take small positive values, $\hat{\pi}_i^s > \hat{\pi}_i^l > \hat{\pi}_i^{fx}$; if γ and θ take intermediate values, $\hat{\pi}_i^s > \hat{\pi}_i^{fx} > \hat{\pi}_i^l$; and if γ and θ take large values, $\hat{\pi}_i^{fx} > \hat{\pi}_i^s > \hat{\pi}_i^l$.*

References

[1] Abe, K., Hattori, K., & Kawagoshi, Y. (2014). Trade liberalization and environmental regulation on international transportation. *Japanese Economic Review*, *65*, 468–82.

[2] Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: an inverted-U relationship. *Quarterly Journal of Economics*, *120*, 701–28.

[3] Aghion, P., Howitt, P., Blundell, R., Prantl, S., & Griffith, R. (2004). Entry and productivity growth: evidence from microlevel panel data. *Journal of the European Economic Association*, *2*, 265–76.

[4] Anderson, J. E., & Van Wincoop, E. (2004). Trade costs. *Journal of Economic Literature*, *42*, 691–751.

[5] Banerjee, S., & Lin, P. (2003). Downstream R&D, raising rival's cost, and input price contracts. *International Journal of Industrial Organization*, *21*, 79–96.

[6] Behrens, K., Gaigné, C., & Thisse, J.-F. (2009). Industry location and welfare when transport costs are endogenous. *Journal of Urban Economics*, *65*, 195–208.

[7] Beladi, H., & Mukherjee, A. (2017). Union bargaining power, subcontracting and innovation. *Journal of Economic Behavior & Organization,137*, 90–104.

[8] Beladi, H., & Oladi, R. (2011). Does trade liberalization increase global pollution? *Resource and Energy Economics*, *33*, 172-78.

[9] Brander, J. A. (1981). Intra-industry trade in identical commodities. *Journal of International Economics*, *11*, 1–14.

[10] Brander, J. A., & Krugman, P. R. (1983). A 'reciprocal dumping' model of international trade. *Journal of International Economics*, *15*, 313–21.

[11] d'Aprémont, C., & Jacquemin, A. (1988). Cooperative and noncooperative R&D in duopoly with spillovers. *American Economic Review*, *78*, 1133–137.

[12] Dewit, G. & Leahy, D. (2016). Strategic R&D commitment and the gain from trade. *Review of International Economics*, *24*, 1129–48.

[13] Francois, J. F., & Wooton, I. (2001). Trade in international transport services: the role of competition. *Review of International Economics*, *9*, 249–61.

[14] Ghosh, A., & Lim, J. (2013). Cooperative and non-cooperative R&D and trade costs. *Journal of International Trade & Economic Development*, *22*, 942–58.

[15] Gilbert, S. M., & Cvsa, V. (2003). Strategic commitment to price to stimulate downstream innovation in a supply chain. *European Journal of Operational Research*, *150*, 617–39.

[16] Haaland, J. I., & Kind, H. J. (2008). R&D policies, trade and process innovation. *Journal of International Economics*, *74*, 170–87.

[17] Hummels, D., Lugovskyy, V., & Skiba, A. (2009). The trade reducing effects of market power in international shipping. *Journal of Development Economics*, *89*, 84–97.

[18] Ishikawa, J., & Tarui, N. (2018). Backfiring with backhaul problem: trade and industrial policies with endogenous transport costs. *Journal of International Economics*, *111*, 81–98.

[19] Kesavayuth, D., & Zikos, V. (2009). Endogenous contracts in unionized oligopoly. *LABOUR*, *23*, 209–35.

[20] Liu, Y., & Mukherjee, A. (2013). The effects of trade liberalization in a vertical structure. *Review of International Economics*, *21*, 966–973.

[21] Long, N. V., Raff, H., & Stähler, F. (2011). Innovation and trade with heterogeneous firms. *Journal of International Economics*, *84*, 149–159.

[22] Maiti, D., & Mukherjee, A. (2013). Trade cost reduction, subcontracting and unionised wage. *Labour Economics*, *21*, 103–110.

[23] Marjit, S., & Mukherjee, A. (2015). Endogenous market structure, trade cost reduction, and welfare. *Journal of Institutional and Theoretical Economics*, *171*, 493–511.

[24] Matsushima, N., & Mizuno, T. (2012). Profit-enhancing competitive pressure in vertically related industries. *Journal of the Japanese and International Economies*, *26*, 142–152.

[25] Matsushima, N., & Takauchi, K. (2014). Port privatization in an international oligopoly. *Transportation Research Part B: Methodological*, *67*, 382–97.

[26] Mukherjee, A., & Pennings, E. (2011). Unionization structure, licensing and innovation. *International Journal of Industrial Organization*, *29*, 232–241.

[27] Shubik, M., & Levitan, R. (1980). *Market Structure and Behavior*. Cambridge: Harvard University Press.

[28] Singh, N., & Vives, X. (1984). Price and quantity competition in a differentiated duopoly. *RAND Journal of Economics*, *15*, 546–554.

[29] Takauchi, K. (2015). Endogenous transport price and international R&D rivalry. *Economic Modelling*, *46*, 36–43.

[30] Zikos, V., & Kesavayuth, D. (2010). Downstream R&D, raising rival's costs, and input-price contracts: a comment on the role of spillovers. *Economics Bulletin*, *30*, 3018–25.

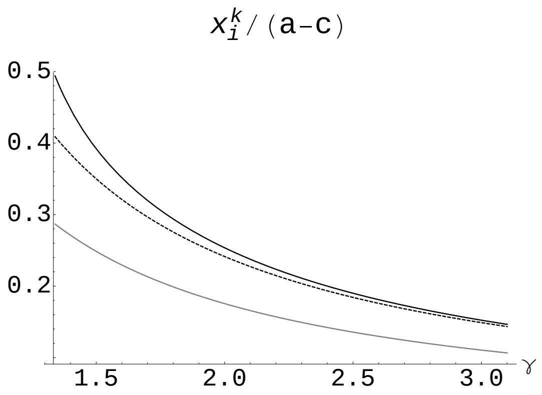


Figure 1: R&D investment

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed line is $k = s$.

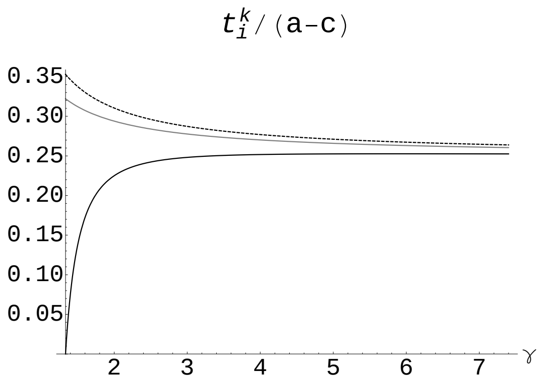


Figure 2: Transport prices

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed line is $k = s$.

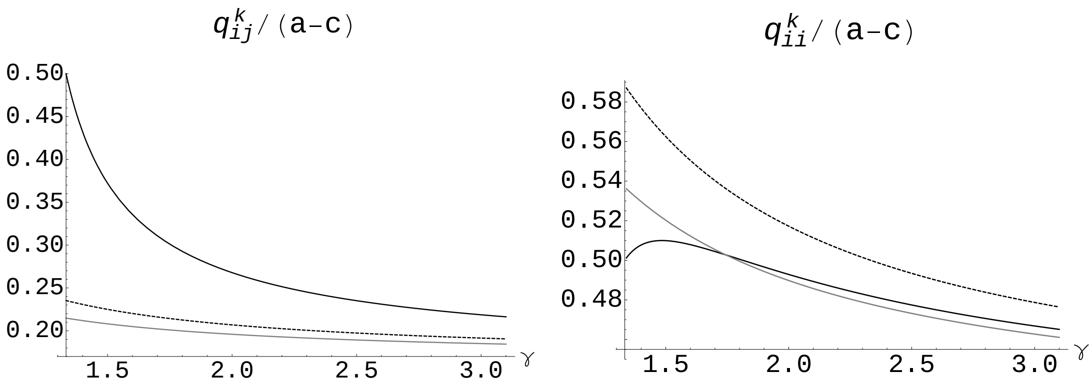


Figure 3: Graph of outputs (Exports on the left; domestic supply on the right)

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed line is $k = s$.

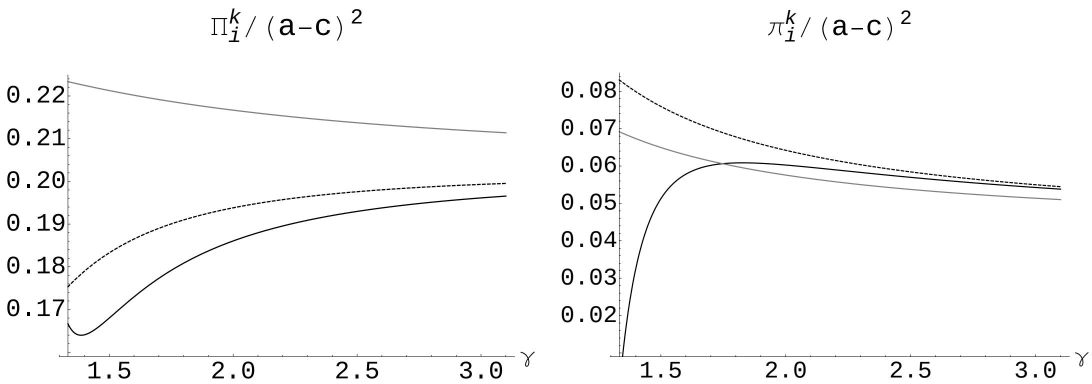


Figure 4: Graph of profits (firm's profit on the left; carrier's profit on the right)

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed line is $k = s$.

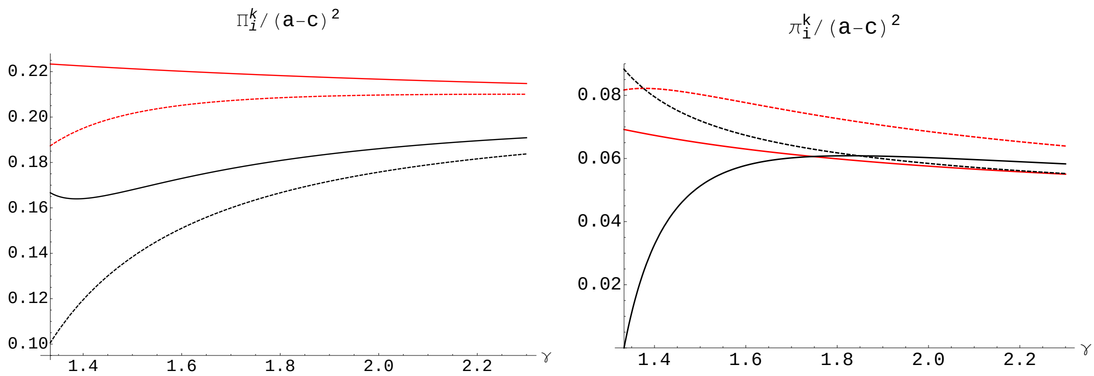


Figure 5: Graph of profits (firm's profit on the left; carrier's profit on the right)

Note: Red line is Π_i^l (π_i^l); Dashed-red line is $\Pi_H^{fx,l} = \Pi_F^{l,fx}$ ($\pi_H^{fx,l} = \pi_F^{l,fx}$); Black line is Π_i^{fx} (π_i^{fx}); Dashed-black line is $\Pi_H^{l,fx} = \Pi_F^{fx,l}$ ($\pi_H^{l,fx} = \pi_F^{fx,l}$).

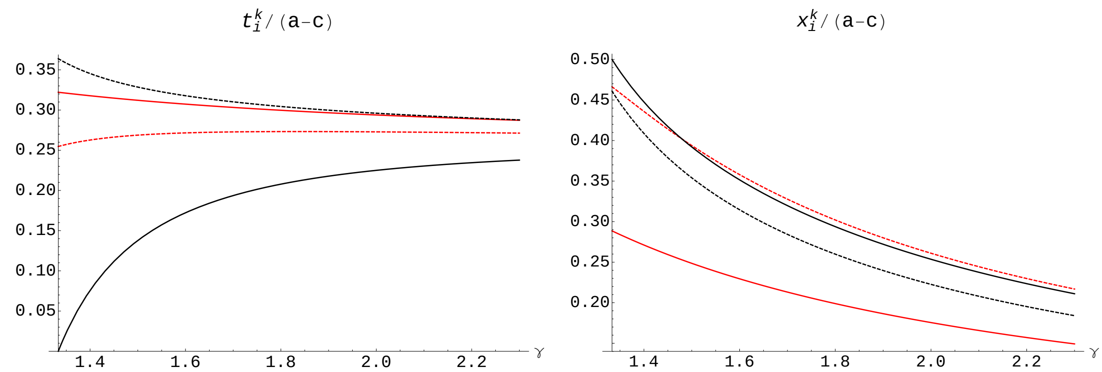


Figure 6: Graph of transport prices and R&D investment (transport prices on the left; R&D investment on the right)

Note: Red line is t_i^l (x_i^l); Dashed-red line is $t_H^{fx,l} = t_F^{l,fx}$ ($x_H^{fx,l} = x_F^{l,fx}$); Black line is t_i^{fx} (x_i^{fx}); Dashed-black line is $t_H^{l,fx} = t_F^{fx,l}$ ($x_H^{l,fx} = x_F^{fx,l}$).

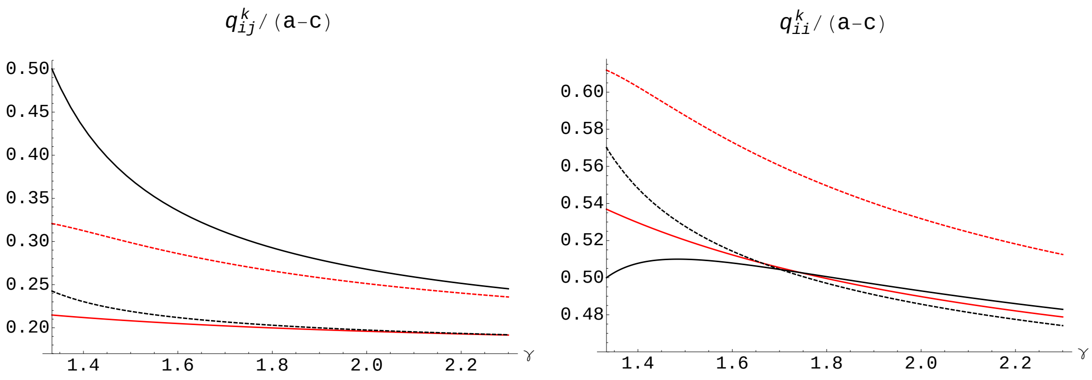


Figure 7: Graph of outputs (exports on the left; domestic supply on the right)

Note: Red line is q^{l}_{ij} (q^{l}_{ii}); Dashed-red line is $q^{fx,l}_{HF} = q^{l,fx}_{FH}$ ($q^{fx,l}_{HH} = q^{l,fx}_{FF}$); Black line is q^{fx}_{ij} (q^{fx}_{ii}); Dashed-black line is $q^{l,fx}_{HF} = q^{fx,l}_{FH}$ ($q^{l,fx}_{HH} = q^{fx,l}_{FF}$).

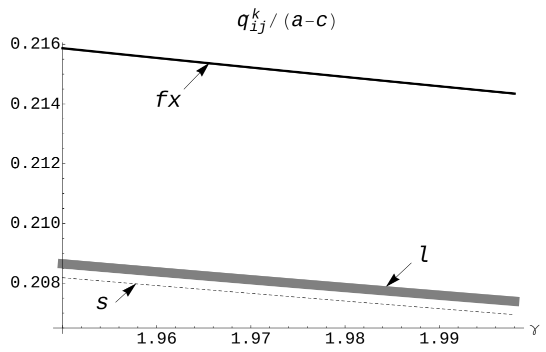
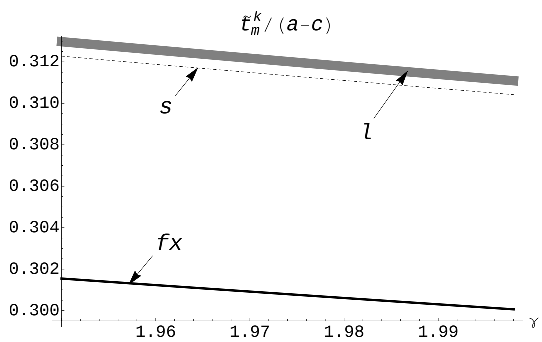


Figure 8: Graph of exports

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed-line is $k = s$.



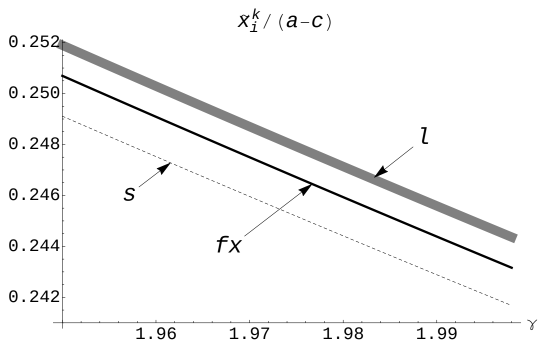


Figure 9: Graph of transport prices and R&D investment (transport prices on the left; R&D investment on the right)

Note: Black line is $k = fx$; Gray line is $k = l$; Dashed-line is $k = s$.

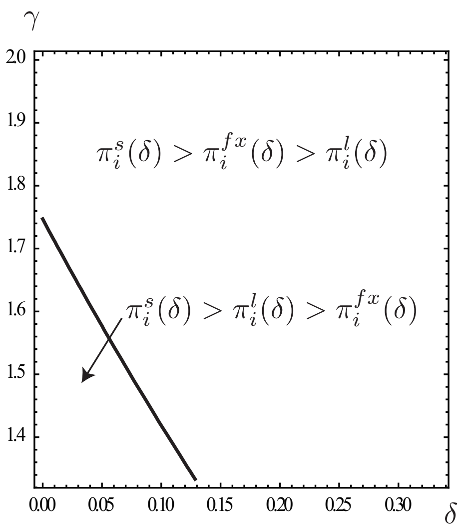


Figure 10: Profit ranking for carrier i with spillover

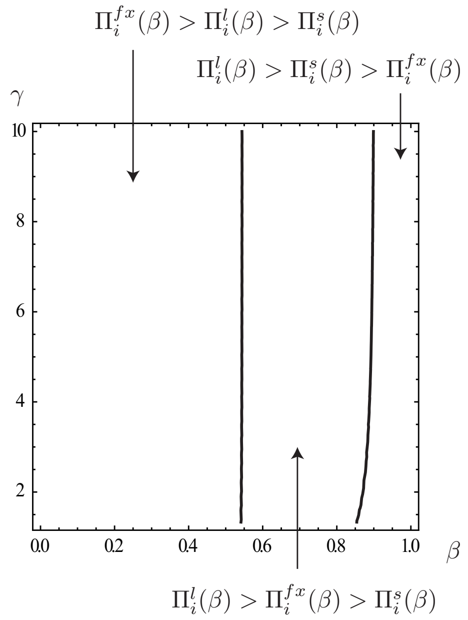


Figure 11: Profit ranking for firm i with product differentiation

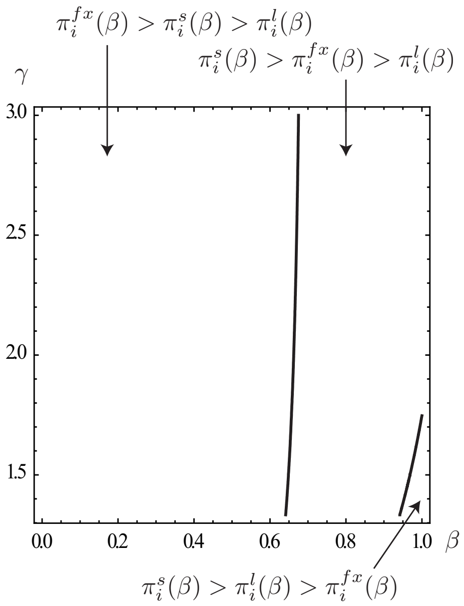


Figure 12: Profit ranking for carrier i with product differentiation

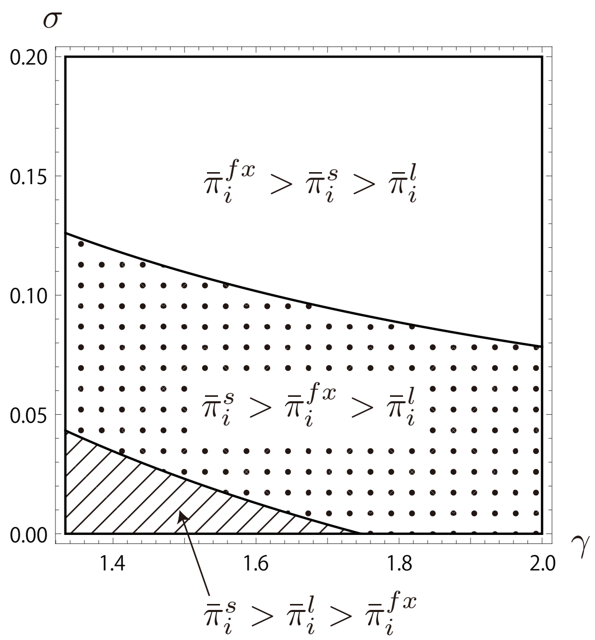


Figure 13: Carrier's profit ranking for $\sigma(q_{ii} + q_{ij})^2$

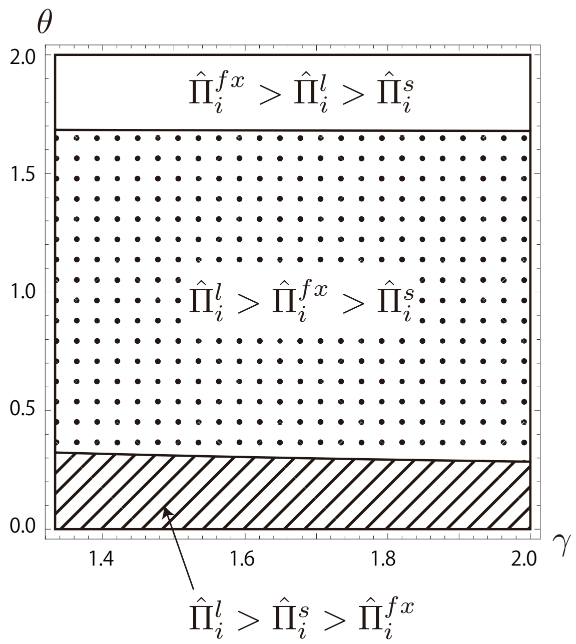
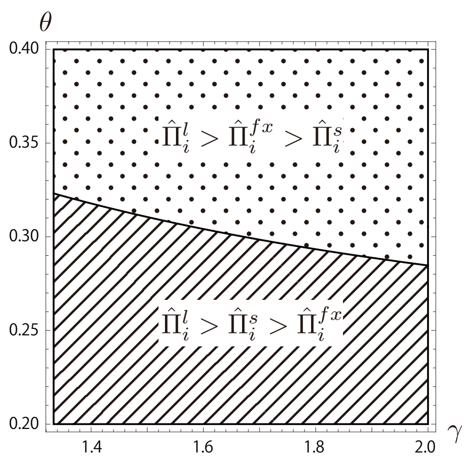


Figure 14: Firm's profit ranking for $\theta(q_{ii}^2 + q_{ij}^2)$



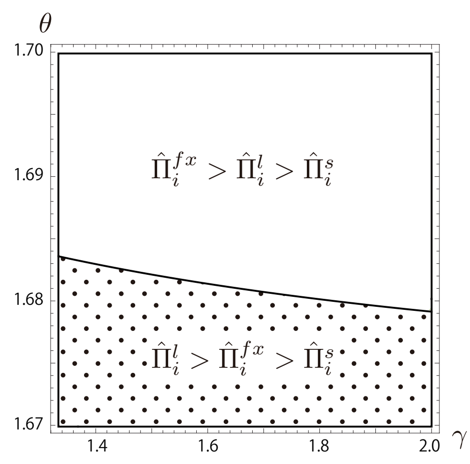


Figure 15: Profit ranking for $\theta \in [0.2, 0.4]$ Figure 16: Profit ranking for $\theta \in [1.67, 1.70]$

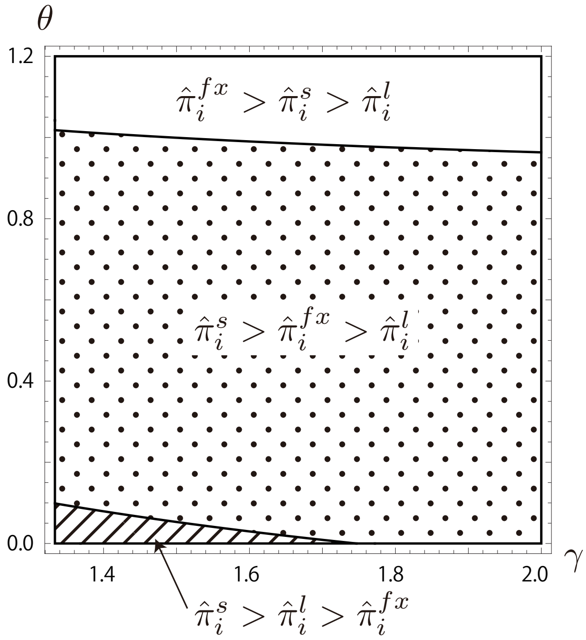


Figure 17: Carrier's profit ranking for $\theta(q_{ii}^2 + q_{ij}^2)$