International R&D rivalry with a shipping firm

Kazuhiro Takauchi[†]

This version: January 5, 2013

Abstract

The purpose of this paper is to consider the role of a monopolistic shipping firm in international research and development (R&D) rivalry. In a two-country, two-firm duopoly with one-way trade, the exporter competes with the local firm in the local market but must pay a per-unit shipping fee to the shipper in order to carry its product. We show that the investment level of the exporter may decrease as the efficiency of R&D improves. To reduce the shipping fee, the exporter commits itself to a smaller investment level but it raises the rival's investment. For this reason, the exporter's investment may decrease as the efficiency of R&D improves. We further investigate a case of two-way trade comprising two symmetric countries. When a single R&D sector undertakes investment for domestic supply and export, producers' investment increase as the efficiency of R&D improves. We show that, in this case, the producers' profit may decrease as the efficiency of R&D improves.

Keywords: Shipping firm, Shipping fee, Efficiency of R&D, Exports
JEL Codes: F12, L13, L91

[†]Corresponding author: Faculty of Economics, Management and Information Science, Onomichi City University, 1600-2 Hisayamada-cho, Onomichi-city, Hiroshima 722-8506, Japan.
E-mail address: kazh.takauch@gmail.com
Tel.: +81-848-22-8311; Fax: +81-848-22-5460

1 Introduction

In international competition among firms, what factors affect exports? At present, it is difficult to freely raise the rate of import tariffs for many countries, and tariff rates are low enough.[1] Historically, the tariff has been considered an important trade cost, but nowadays, this is not necessarily true: a main that prevents export activity is not import tariff but transport price.[2] As shown by Hummels (2007) and Hummels et al. (2009), maritime transport price has a particularly important role in exports. First, as pointed out by Hummels (2007), the air transport price smoothly decreases, but the ocean freight rate does not decrease over time. Second, as empirically shown by Hummels et al. (2009), the ocean freight rate is a mark-up price, and as such, the shipping firm has a certain monopoly power.

The other factor that possibly affects firm export activity is its productivity. In general, the productivity of a firm can be improved by its cost-reducing innovation. To invest in cost-reducing research and development (R&D), firms utilize a smaller level of the production cost.[3] Because a smaller production cost directly corresponds to a larger volume of output, firms can export larger volumes than earlier. For example, as empirically shown by Yasar et al. (2006), firm-level productivity enhancement results in higher export performance.[4] Moreover, less expenditure into R&D reduces production cost if the efficiency of R&D improves. Thus, the efficiency of investment possibly affects firm export.

The purpose of this paper is to consider the relationship among endogenously decided shipping fee, cost-reducing innovation, and firm export. To examine the strategic interaction among them, we introduce a monopoly shipper in an international cost-reducing R&D rivalry model. There are two producers, an exporter and a local firm, and a non-producer,

---

[1] Anderson and Wincoop (2004) indicate that the arithmetic average rate of tariff is less than 5% for rich countries.

[2] Clark et al. (2004) point out that transport prices are a greater barrier to U.S. markets than import tariffs for most Latin American countries.

[3] There are many studies on international R&D rivalry. For example, see Spencer and Brander (1983), Leahy and Neary (1996, 1999), Qiu and Tao (1998), Dewit and Leahy (2004), Kujal and Ruiz (2007, 2009), Haaland and Kind (2008), and Takauchi (2011). They focus on the effects of R&D subsidy policy, the spillover effects of investment, and the interactions between other trade policies and firms' R&D incentives.

[4] They examine the relationship between export and productivity for Turkish manufacturing industries.

a shipping firm. The exporter and the local firm compete *à la* Cournot in the market of the local country and engage in cost-reducing R&D activity, whereas the monopoly shipper carries the product produced by the exporter to the market of the local country. The timing of the game is as follows. In the first stage, each producer invests in cost-reducing R&D, respectively. In the second stage, the shipper decides the shipping fee. In the final stage, each producer decides the quantity of its product.

We show that if R&D is highly efficient, the exporter's investment decreases as the efficiency of R&D improves. The key to this result is that the shipping fee decreases as the exporter's investment decreases. For this reason, to reduce the fee, the exporter commits to a smaller level of investment. Because this commitment also increases the rival's investment level, the exporter's investment decreases when the rival has larger incentives to invest.

We further extend the above one-way trade to a two-way (or intra-industry) trade comprising two symmetric countries. In contrast to the above one-way trade, the producer located in each country has two different plants: one for domestic supply and the other for export. When the producer located in each country exports to the other country, it must pay a shipping fee to the monopoly shipper. We show that if the result of R&D can be commonly used across different plants (i.e., a single R&D sector can implement cost-reducing innovation across the two plants), the producers' profit decreases as the efficiency of R&D goes up over a critical level. In this case, producers do not commit to a smaller level of investment in order to reduce the shipping fee. Thus, equilibrium investments increase as the efficiency of R&D improves. This yields that an increase in the equilibrium total outputs is smaller than that in investments. Since the difference between them becomes larger when R&D is highly efficient, the producers' profit decreases when the efficiency goes up over a critical revel. In a usual cost-reducing R&D rivalry, the investments, outputs, and profit increase as the efficiency of R&D improves. However, our results imply that producers' technology improvement does not always enhance their activities; in particular, an improvement in production efficiency may reduce the producers' profit. This can be seen in the strategic interaction between the producers' technology improvement and the

endogenous freight rate, and thus, we can say that our results provide a new insight in the study of transportation and international trade.

A number of works focus on international transportation and freight rate (Francois and Wooton, 2001; Behrens and Picard, 2011; Kleinert and Spies, 2011).[5] Although these studies are seminal works that focus on the market power of the transport industry, they do not examine the relationship between the producer's process innovation and freight rates.

This paper is related to some studies on upstream-downstream oligopoly with R&D (Banerjee and Lin, 2003; Ishii, 2004; Mukherjee and Ray, 2007; Matsuhima and Mizuno, 2012). They consider the cost-reducing innovation of input suppliers or final-good manufactures in a vertically related market. In these vertical structures of production, to produce a final-good, the downstream agent always purchases the input from the upstream supplier. However, in our international transporting structure, the producer pays a per-unit shipping fee when exporting its product to the designation country. Thus, these models of upstream-downstream oligopoly do not cover international transportation.

Some works on unionized oligopoly with R&D are also related to this paper (Calabuig and Gonzalez-Maestre, 2002; Haucap and Wey, 2004; Mukherjee et al., 2007; Manasakis and Petrakis, 2009; Mukherjee and Pennings, 2011). In our model, the shipper sets the freight rate in a manner similar to that employed in the above labor union model: the shipper decides the freight rate (the per-unit fee on shipment) and the labor union decides the wedge rate (the per-unit fee on the usage of labor). However, our model is crucially different from the above labor union model. First, in the above studies, it is assumed that each firm has a union or that all firms have a common union. In our model, the only exporter (or the plant exporting) must use the shipper and pays the freight rate. This point is fundamentally different from these studies.[6] Second, they focus on the role of

[5]There is an another study which focuses on the international transportation. Matsushima and Takauchi (2012) focus on the role of ports and international shipment in a two-way oligopoly. They examine that the choice of ownership structure in an international port (privatization or nationalization) possibly works as a strategic trade policy, which controls trade volumes.

[6]Although Calabuig and Gonzalez-Maestre (2002) and Haucap and Wey (2004) consider a unionized industry, they do not examine a standard cost-reducing R&D rivalry. In particular, Haucap and Wey (2004) assume a patent tournament of two firms: they have a chance to get exclusive rights to an innovation, which can reduce the labor requirement. In contrast, Mukherjee et al. (2007) and Mukherjee and Pennings

spillover effects of investment, but tend to neglect the roll of the efficiency of R&D.[7]

In the next section, we build a simple one-way trade model. Section 3 derives the equilibrium outcomes and examines firms' investment and output strategies and section 4 discusses the case of Brander and Krugman (1983)-type two-way trade. Section 5 offers a conclusion.

2   Model

We consider a one-way trade model with a shipping firm. There are two countries, local and foreign. The local country has a product market, but the foreign one does not. We call the foreign country an exporting country. Two producers (an exporter and a local firm) and a shipper exist in the world, and the exporter (local firm) is in the exporting (local) country. The exporter and the local firm compete *à la* Cournot in the local country's market. We assume that the local firm supplies its product without a shipping fee. In contrast, since the exporter is located overseas, it must use the shipper to carry its product to the local market across the ocean. To transport the product, the exporter must pay the per-unit shipping fee, f, to the shipper.[8]

Before market competition, the exporter and the local firm engage in cost-reducing R&D competition without spillover. The unit production cost is c (> 0), and is the same for both the exporter and the local firm.[9] To reduce the initial unit cost, all producers make cost-reducing investments. After investment, the unit cost becomes $c - x_i$, where x_i is the investment level of producer i. Variables associated with the two producers are subscripted by $i = E, L$ (exporter and local firm). We assume that the R&D cost function is $(\gamma/2)(x_i)^2$, where γ is the efficiency of R&D and a positive constant.[10] That is, a smaller

(2011) mainly focus on the technology licensing of downstream manufactures.

[7]For example, Manasakis and Petrakis (2004) consider the relationship between the spillover effects of investment and the formation of research joint ventures in duopoly firms.

[8]As empirically demonstrated by Hummels et al. (2004), transport prices are not ad valorem (i.e., iceberg)-type but per-unit type.

[9]Because our focus is not on cost asymmetry, we assume that the two producers have the same production technology.

[10]This type of R&D cost function is popular. For example, see Leahy and Neary (1996, 1999), Qiu and Tao (1998), Dewit and Leahy (2004), Motta (2004), Kujal and Ruiz (2009), Takauchi (2011), and Matsushima and Mizuno (2012).

γ corresponds to a higher efficiency in R&D.

The inverse market demand function in the local country is given by

$$p = a - q_E - q_L,$$

where p is the product price, q_E is the export quantity of the exporter, q_L is the output of the local firm, a is a positive constant, and $a > c$. Thus, the profit of producer i, Π_i, is given by

$$\Pi_E \equiv [a - (q_E + q_L) - (c - x_E) - f] \, q_E - \frac{\gamma}{2}(x_E)^2, \tag{1}$$

$$\Pi_L \equiv [a - (q_E + q_L) - (c - x_L)] \, q_L - \frac{\gamma}{2}(x_L)^2. \tag{2}$$

The shipper makes a take-it-or-leave-it offer to the exporter and decides the per-unit shipping fee, f. The profit of the shipper, π_S, is given as

$$\pi_S \equiv (f - f_0) \, q_E, \tag{3}$$

where f_0 is the minimum price of shipment. For simplicity, we normalize f_0 to zero.[11]

To examine the strategic interaction between the shipper and producers, we consider the following three-stage game. At stage 1, the exporter and local firm independently and simultaneously choose a volume of R&D investment. At stage 2, the shipper sets the shipping fee. At stage 3, the exporter and local firm compete à la Cournot in the local market.

This timing of the game reflects the planning time relevant to players' decisions. In general, the decision on investment has a much longer time while the shipping fee is negotiated for a shorter time. Since quantities in the product market can be adjusted for the shortest time among all decisions, the decision on production quantities is done in the final stage of the game.

We use the subgame perfect Nash equilibrium as the equilibrium concept. The game

---

[11]This specification does not alter our results.

is solved by backward induction.

3   Equilibrium outcomes in one-way trade

In this section, we derive the equilibrium outcomes and examine the strategies of the producers and the shipper.

Third stage. Two producers compete *à la* Cournot in the market of the local country. Using (1) and (2), the FOC for the profit maximization of each producer is

$$\text{Exporter:} \quad 0 = a - c - f - 2q_E - q_L + x_E,$$

$$\text{Local firm:} \quad 0 = a - c - q_E - 2q_L + x_L.$$

The above equations yield the following outputs in the third stage:

$$q_E(x_E, x_L, f) = \frac{a - c - 2f + 2x_E - x_L}{3}; \quad q_L(x_E, x_L, f) = \frac{a - c + f - x_E + 2x_L}{3}. \quad (4)$$

Second stage. In the second stage, the shipper chooses a level of the shipping fee, f. From (3) and (4), the shipper maximizes $fq_E(x_E, x_L, f)$ for the shipping fee. The FOC is

$$0 = -\frac{2}{3}f + \frac{1}{3}(a - c - 2f + 2x_E - x_L).$$

Solving the FOC for f, we obtain the shipping fee in the second stage:

$$f(x_E, x_L) = \frac{a - c + 2x_E - x_L}{4}. \quad (5)$$

Thus, the shipping fee rises (falls) as the volume of R&D investment by the exporter increases (decreases).

In the second stage, from (4) and (5), the outputs of the producers are

$$q_E(x_E, x_L) = \frac{a - c + 2x_E - x_L}{6}; \quad q_L(x_E, x_L) = \frac{5(a - c) - 2x_E + 7x_L}{12}. \quad (6)$$

First stage. Here, let the asterisks denote the subgame perfect Nash equilibrium of the game. In the first stage, producers choose their respective volumes of R&D investment. Using (1), (2), (5), and (6), the FOCs in this R&D stage are

$$\text{Exporter:} \quad 0 = a - c + (2 - 9\gamma)x_E - x_L,$$

$$\text{Local firm:} \quad 0 = 35(a - c) - 14x_E + (49 - 72\gamma)x_L.$$

The above equations yield the equilibrium levels of R&D investments, x_E^* and x_L^* (equation (8), below). The equilibrium outputs, investments, and profit of the producers are

$$q_E^* = \frac{6(a-c)\gamma(6\gamma-7)}{28 - 195\gamma + 216\gamma^2}; \quad q_L^* = \frac{6(a-c)\gamma(15\gamma-4)}{28 - 195\gamma + 216\gamma^2}, \tag{7}$$

$$x_E^* = \frac{4(a-c)(6\gamma-7)}{28 - 195\gamma + 216\gamma^2}; \quad x_L^* = \frac{7(a-c)(15\gamma-4)}{28 - 195\gamma + 216\gamma^2}, \tag{8}$$

$$\Pi_E^* = \frac{4(a-c)^2(6\gamma-7)^2\gamma(9\gamma-2)}{(28 - 195\gamma + 216\gamma^2)^2}; \quad \Pi_L^* = \frac{(a-c)^2(15\gamma-4)^2\gamma(72\gamma-49)}{2(28 - 195\gamma + 216\gamma^2)^2}. \tag{9}$$

The equilibrium shipping fee and the profit of the shipper are

$$f^* = \frac{9(a-c)\gamma(6\gamma-7)}{28 - 195\gamma + 216\gamma^2}; \quad \pi_S^* = \frac{54(a-c)^2\gamma^2(6\gamma-7)^2}{(28 - 195\gamma + 216\gamma^2)^2}. \tag{10}$$

We make the following two assumptions.

Assumption 1. *The efficiency of R&D is not too high, i.e., $\gamma > \underline{\gamma} \equiv 7/6$.*

To ensure positive quantities for all outcomes in the game, we require this assumption. Note that this is a stronger condition on γ than the condition required to satisfy the SOCs in both the R&D and fee-setting stages.[12] Thus, all other conditions are satisfied as long as Assumption 1 holds.

Assumption 2. *The unit production cost, c, satisfies $c/(a-c) > x_L^*/(a-c)$.*

To ensure that the ex-post unit production cost has a positive value (i.e., $c - x_i^* > 0$),

---

[12]The SOC for profit maximization in the R&D stage is $\gamma > 2/9 \simeq 0.22222$ for the exporter and $\gamma > 49/72 \simeq 0.680556$ for the local firm.

it suffices to consider Assumption 2. This is because among all of R&D investments, the biggest R&D investment is x_L^* and it is monotonically decreasing with γ.[13]

The above (7)–(9) yield the following proposition.

Proposition 1. *(i) When R&D is highly efficient, the volume of R&D investment of the exporter decreases as the efficiency of R&D improves; otherwise, it increases as the efficiency of R&D improves, i.e., $\partial x_E^*/\partial \gamma > 0$ if $\gamma < \widehat{\gamma} \equiv (1/12)(3\sqrt{7} + 14) \simeq 1.8281$ but $\partial x_E^*/\partial \gamma \leq 0$ if $\gamma \geq \widehat{\gamma}$. However, the volume of R&D investment of the local firm increases as the efficiency of R&D improves. (ii) The output and profit of the exporter decrease, but those of the local firm increase as the efficiency of R&D improves.*

Proof. See Appendix A.

Figure 1 illustrates the shapes of the equilibrium investments of the exporter and the local firm for γ (equation (8)).

[Insert Figure 1 here]

In a usual cost-reducing R&D competition, the volume of investment increases as the efficiency of R&D improves.[14] Thus, one might think that the result shown in Proposition 1 is in sharp contrast to the intuition. When R&D is highly efficient, why does the exporter reduce the volume of investment as the efficiency of R&D improves? The logic behind this result depends on two factors. The first is that the economy of scale works in R&D investment; the effect is stronger if R&D is highly efficient. The second is that R&D investment works as a commitment device for the shipping fee; to commit to a smaller level of investment reduces the shipping fee, which decreases as the exporter's investment level decreases.

In the R&D stage, each producer will invest heavily if it believes it can sell heavily. Furthermore, since a smaller γ corresponds to a higher R&D efficiency, investment incentives are larger. The exporter must pay the shipping fee, and thus, it has a smaller

---

[13]For example, when we set $a - c = 1$, $c \geq 1$ suffices Assumption 2 for any $\gamma > \underline{\gamma}$.

[14]For example, see Motta (2004, Ch. 2).

market share than the local firm. That is, since the local firm has an advantage in market competition, the local firm invests actively if the efficiency of R&D is high (i.e., γ is low).

The second factor promotes the effects of the scale economy. Because the investment level is decided in the first stage of the game, the exporter can control the shipping fee. From (5), a reduction in x_E directly reduces the shipping fee and increases the local firm's investment level (i.e., strategic substitutes in the R&D stage). To reduce the shipping fee, the exporter always commits to a smaller level of investment; this behavior induces a larger level of investment by the local firm. When the efficiency of R&D is high, the effects of a smaller investment considerably increase the local firm's investment and further reduce the investment level of the exporter. Therefore, if γ becomes smaller than the critical level, $\widehat{\gamma}$, then the investment level of the exporter falls.

From (10), we establish the following proposition.

Proposition 2. *(i) The shipping fee rises and becomes $(1/4)(a-c)$ as the efficiency of R&D becomes worse. (ii) The profit of the shipper increases as the efficiency of R&D becomes worse.*

Proof. (i) Differentiating f^* with respect to γ, we obtain

$$\frac{\partial f^*}{\partial \gamma} = \frac{18(a-c)(-98 + 168\gamma + 171\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2}.$$

From the numerator of the above equation, $-98 + 168\gamma + 171\gamma^2 \geq 0$ for all $\gamma \geq (7/57)(3\sqrt{6} - 4) \simeq 0.411$. Hence, $\partial f^*/\partial \gamma > 0$. Rearranging f^*, we have $\lim_{\gamma \to \infty} f^* = (1/4)(a-c)$.
(ii) Differentiating π_S^* with respect to γ, we obtain

$$\frac{\partial \pi_S^*}{\partial \gamma} = \frac{216(a-c)^2\gamma(6\gamma - 7)(-98 + 168\gamma + 171\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^3} > 0.$$

These results imply Proposition 2. Q.E.D.

Figure 2 illustrates the equilibrium shipping fee and the profit of the shipper for γ (equation (10)).

[Insert Figure 2 here]

The reason is explained by a simple mechanism. In Proposition 1, we find that the output of the exporter decreases as the efficiency of R&D improves. This reduction in export volume corresponds to the shipping fee. This is because the shipper and the exporter have a certain cooperative relationship. Since a shipper's profit directly depends on the output of the exporter, to ensure positive production for the exporter, the shipper reduces its fee when the exporter is extremely weak. Hence, the profit of the shipper also goes down as the output of the exporter goes down.

In a cost-reducing R&D competition, investment is not performed if the cost of R&D increases indefinitely (i.e., $x_i \to 0$ as $\gamma \to \infty$). That the shipping fee has an upper limit corresponds to this fact.

In addition, we immediately find the following result.

Lemma 1. *Total investment, $x_E^* + x_L^*$, and total output, $q_E^* + q_L^*$, increase as the efficiency of R&D improves.*

Proof. From (8), differentiating $x_E^* + x_L^*$ with respect to γ, we obtain

$$\frac{\partial(x_E^* + x_L^*)}{\partial \gamma} = -\frac{36(a-c)(203 - 672\gamma + 774\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2} < 0.$$

From (7), differentiating $q_E^* + q_L^*$ with respect to γ, we obtain

$$\frac{\partial(q_E^* + q_L^*)}{\partial \gamma} = -\frac{6(a-c)(308 - 1176\gamma + 1719\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2} < 0.$$

Therefore, Lemma 1 holds. Q.E.D.

Lemma 1 implies that the local firm plays a major role but the exporter plays a minor role in view of the local country's domestic welfare. Because the exporter must pay the shipping fee and the market share of the firm is considerably smaller than that of the local firm, the effects of a change in γ on the local firm undoubtedly dominate that on the exporter. For this reason, the consumers' surplus in the local country strictly increases

10

as the efficiency of R&D improves. Further, the domestic welfare of the local country is comprised by the consumers' surplus and the local firm's profit, and as such, the welfare also increases as the efficiency of R&D improves.[15]

4 Two-way trade

This section refers to Brander and Krugman (1983)-type two-way (or intra-industry) trade. In the previous section, we have been obtained interesting results (propositions 1 and 2). However, do these results also hold in the case of two-way trade?

As it turns out, our results of one-way trade do not depend on the trade structure, whether one-way or two-way. The key factor that controls our results is whether the investment in R&D works as a *commitment device* for the shipper (decision of fee-setting) or not. In two-way trade with process innovation, each producer located in each country has two different plants: one for domestic supply and the other for export. If each plant invests, the investment for exporting can work as the commitment device for the shipper. When we consider the technical training and skills of the employees of each plant, the enhancement in these employee attributes (the result of cost-reducing R&D) is exclusively used in that plant. In addition, each plant is operated by a specific technique unique to it is the same. In these cases, since it is difficult to use common knowledge across two different plants, each plant invests to reduce its own production cost. In contrast, if the result of R&D can be commonly used across both plants (i.e., a single R&D sector implements cost-reducing innovation across two plants), the investments do not work as a commitment device for the shipper.[16]

Hence, we consider the following two cases related to the result of R&D: one is that the result of R&D cannot be commonly used across different plants (Case 1), and the other is that it can be commonly used (Case 2).

First, let us consider the following situation: there are two symmetric countries with a homogeneous product market, Home (H) and Foreign (F). In each country, one producer

---

[15]The effects of γ on the welfare of the local country are derived in Takauchi (2012).

[16]It is often assumed that a single R&D sector implements cost-reducing innovation across two plants. For example, see Haaland and Kind (2008).

exists and each producer i $(= H, F)$ produces a product for domestic supply and to export it to another market (the market in each country is segmented). To carry its product to the destination country, each producer pays a per-unit shipping fee, g, to the monopoly shipper: the shipper charges a common shipping-fee for both producers. We define that the subscript represents the flow of the product: "HH" denotes Home-to-Home and "HF" denotes Home-to-Foreign; that is, q_{HH} is the domestic supply of producer H and q_{HF} is the export by producer H from Home to Foreign. The shipper transports q_{HF} units of the product from Home to Foreign and q_{FH} units of the product from Foreign to Home. The profit of the shipper is $\overline{\pi}_S \equiv (q_{HF} + q_{FH})g$.

The inverse market demand function in each country is $p_i = a - q_{ii} - q_{ji}$, where $i \neq j$ and $i, j = H, F$. The timing of the game is the same as in the previous section.

Case 1. The result of R&D cannot be commonly used across different plants:
In this case, R&D is implemented in each plant. The profit of producer i $(= H, F)$ is given by

$$\Pi_i \equiv \underbrace{[p_i - (c - x_{ii})]q_{ii} - \frac{\gamma}{2}(x_{ii})^2}_{\text{Domestic supply}} + \underbrace{[p_j - (c - x_{ij}) - g]q_{ij} - \frac{\gamma}{2}(x_{ij})^2}_{\text{Export}}, \qquad (11)$$

where $i \neq j$ and $i, j = H, F$.

Adopting a similar method as in the previous section, from (11), we obtain the following equilibrium values:[17]

$$x_{ii}^D = \frac{5(a-c)(5\gamma - 2)}{10 - 51\gamma + 48\gamma^2}; \quad x_{ij}^D = \frac{2(a-c)(4\gamma - 5)}{10 - 51\gamma + 48\gamma^2}; \quad q_{ii}^D = \frac{4(a-c)\gamma(5\gamma - 2)}{10 - 51\gamma + 48\gamma^2},$$

$$q_{ij}^D = \frac{2(a-c)\gamma(4\gamma - 5)}{10 - 51\gamma + 48\gamma^2}; \quad \Pi_i^D = \frac{(a-c)^2\gamma(-200 + 988\gamma - 1649\gamma^2 + 928\gamma^3)}{2(10 - 51\gamma + 48\gamma^2)^2},$$

$$g^D = \frac{3(a-c)\gamma(4\gamma - 5)}{10 - 51\gamma + 48\gamma^2}; \quad \overline{\pi}_S^D = \frac{12(a-c)^2\gamma^2(4\gamma - 5)^2}{(10 - 51\gamma + 48\gamma^2)^2}, \qquad (12)$$

where superscript "D" denotes the equilibrium values in Case 1.[18] To ensure positive quantities, here, we need $\gamma > 5/4$.

---

[17]For details of the derivation, see Appendix B.
[18]In Case 1, we assume that $c/(a-c) > x_{ii}^D/(a-c)$.

From (12), we find that $\partial q_{ij}^D/\partial \gamma > 0$, $\partial g^D/\partial \gamma > 0$, and $\partial \overline{\pi}_S^D/\partial \gamma > 0$.[19] Moreover, the differentiation of x_{ij}^D yields

$$\frac{\partial x_{ij}^D}{\partial \gamma} = -\frac{2(a-c)(215 - 480\gamma + 192\gamma^2)}{(10 - 51\gamma + 48\gamma^2)^2} \quad \text{for} \quad i \neq j.$$

Therefore, $\partial x_{ij}^D/\partial \gamma > (\leq) 0$ if $\gamma < (\geq) \gamma^D \equiv (1/24)(\sqrt{255} + 30) \simeq 1.91536$.

Case 2. The result of R&D can be commonly used across different plants: Since a single R&D sector implements cost-reducing investment in both plants, the profit of producer i is given by

$$\Pi_i \equiv [p_i - (c - x_i)]q_{ii} + [p_j - (c - x_i) - g]q_{ij} - \frac{\gamma}{2}(x_i)^2, \tag{13}$$

where x_i denotes the volume of investment by producer i.

From (13), the equilibrium values become as

$$q_{ii}^C = \frac{60(a-c)\gamma}{144\gamma - 113}; \quad q_{ij}^C = \frac{24(a-c)\gamma}{144\gamma - 113}; \quad x_i^C = \frac{113(a-c)}{144\gamma - 113},$$
$$\Pi_i^C = \frac{(a-c)^2\gamma(8352\gamma - 12769)}{2(144\gamma - 113)^2},$$
$$g^C = \frac{36(a-c)\gamma}{144\gamma - 113}; \quad \overline{\pi}_S^C = \frac{1728(a-c)^2\gamma^2}{(144\gamma - 113)^2}, \tag{14}$$

where superscript "C" denotes the equilibrium values in Case 2.[20] To ensure positive quantities, here, we need $\gamma > 12769/8352 \simeq 1.5289$.

From (14), we find that $\partial q_{ii}^C/\partial \gamma < 0$, $\partial q_{ij}^C/\partial \gamma < 0$, $\partial x_i^C/\partial \gamma < 0$, $\partial q^C/\partial \gamma < 0$, and $\partial \overline{\pi}_S^C/\partial \gamma < 0$.[21] In contrast, the derivation of producer's profit Π_i^C yields

$$\frac{\partial \Pi_i^C}{\partial \gamma} = \frac{113(a-c)^2(12769 - 432\gamma)}{2(144\gamma - 113)^3}.$$

From the above equation, $\partial \Pi_i^C/\partial \gamma \geq (<) 0$ if $\gamma \leq (>) \gamma^C \equiv 12769/432 \simeq 29.5579$.

---

[19] For these results, see Appendix D.

[20] In Case 2, we assume that $c/(a-c) > x_i^C/(a-c)$.

[21] See also Appendix D.

Summarizing the above arguments, we establish the following result in the case of symmetric two-way trade.

Proposition 3. *(i) Suppose that the result of R&D is commonly used across different plants (Case 2). Then, if $\gamma < \gamma^C \equiv 12769/432$, the profit of the producers decreases as the efficiency of R&D improves. (ii) Suppose that the result of R&D is not commonly used across different plants (Case 1). Then, if $\gamma < \gamma^D \equiv (1/24)(\sqrt{255} + 30)$, the producers' R&D investments for exporting decrease as the efficiency of R&D improves; the shipping fee and each producer's exports decrease as the efficiency of R&D improves.*

[Insert Figure 3 here]

Why does the profit of the producers decrease as the efficiency of R&D improves? The reason is that investments increase faster than total outputs for an improvement in the efficiency of R&D. To see this, we derive the following relation:

$$\Delta_{xq}^C \equiv \left| \frac{\partial x_i^C}{\partial \gamma} \right| - \left| \frac{\partial (q_{ii}^C + q_{ij}^C)}{\partial \gamma} \right| = \frac{6780(a-c)}{(144\gamma - 113)^2} > 0; \quad \frac{\partial \Delta_{xq}^C}{\partial \gamma} = -\frac{1952640(a-c)}{(144\gamma - 113)^3} < 0.$$

The result is explained by the following logic. The producers do not decrease investment in order to reduce the shipping fee, and thus, the investment increases as the efficiency of R&D improves ($\partial x_i^C / \partial \gamma < 0$). This is because, reducing investments implies that they are crowded out in the investment stage (strategic substitution of R&D rivalry), so producers tend to increase those investments in equilibrium. This corresponds to the shipping fee increasing as the efficiency of R&D improves ($\partial g^C / \partial \gamma < 0$).

The producers' outputs increase from the improved efficiency of R&D ($\partial q_{ii}^C / \partial \gamma < 0$ and $\partial q_{ij}^C / \partial \gamma < 0$). Since the producers engage in Cournot competition, rising (reducing) rival's cost increases (decreases) one's output. Therefore, an increase in the rival's investment reduces one's domestic supply and export. One's domestic supply increases as γ decreases, but a reduction in γ increases the rival's investment too.[22] An increase in domestic supply

---

[22]The third stage equilibrium values are $q_{ii}(x_i, x_j, g) = (1/3)(a - c + g + 2x_i - x_j)$ and $q_{ij}(x_i, x_j, g) = (1/3)(a - c - 2g + 2x_i - x_j)$ for $i \neq j$. Further, see Appendix C.

14

from an improvement in the efficiency of R&D is not so large. One's export also increases as γ decreases, but a reduction in γ increases both the rival's investment and the shipping fee. For this reason, an increase in export from an improvement in the efficiency of R&D is small. Furthermore, if γ is small enough, the cost of investments becomes smaller and their enhancement becomes stronger. Therefore, if the efficiency of R&D goes up over a critical level, $\gamma^C \equiv 12769/432 \simeq 29.5579$, the producers' profit decreases.

5 Conclusion

This paper builds a model of international R&D rivalry with a monopoly shipper. Although the shipping fee (i.e., maritime transport price) and the productivity of the exporters are important factors that possibly affect export behavior, the interactions among them have not received much attention. We show that the exporter's investment level may decrease as the efficiency of R&D improves. The key to this result is whether the R&D investments work as a commitment device for the shipper or not. To reduce the shipping fee, the exporter commits to a smaller investment level. Because this commitment raises the rival's investment level, the exporter's investment decreases. In two-way trade, we also find that if the result of R&D is commonly used across different plants (i.e., a single R&D sector implements cost-reducing innovation across two plants), the profit of the producers may decrease as the efficiency of R&D improves. When R&D is highly efficient, the increase in outputs is smaller than that of investments due to the improvement in the R&D efficiency. Then, a higher efficiency of R&D corresponds to a smaller profit for the producers.

In process innovation, the efficiency of investment plays an important role. If efficiency improves, investment incentives and output increase. This undoubtedly increases the profit of the producers. However, our findings highlight some paradoxical results, which occur if R&D is highly efficient. Since all these findings depend on the behavior of the shipper, we believe that our model developed herein offers a new insight into transportation and international trade.

In this study, we have focused on the relationship between the productivity of the pro-

ducers and the shipping fee by considering these producers' investment activities. However, one might think that the process innovation is not always done only by producers; non-producers may do it. The strategic interaction of R&D activity among producers and non-producers surpasses the scope of our analysis, and as such, we have not considered the investment activity of the shipper. This issue may be fruitful for future research.

Acknowledgments

Appendix

A. Proof of Proposition 1 (i) Differentiating (8) with respect to γ, we obtain

$$\frac{\partial x_E^*}{\partial \gamma} = -\frac{36(a-c)(133 - 336\gamma + 144\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2}, \quad \frac{\partial x_L^*}{\partial \gamma} = -\frac{504(a-c)(5 - 24\gamma + 45\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2}.$$

From the numerator of $\partial x_E^*/\partial \gamma$, $133 - 336\gamma + 144\gamma^2 \geq 0$ for $\gamma \geq (1/12)(3\sqrt{7}+14) \simeq 1.8281$ and $\gamma \leq (1/12)(-3\sqrt{7}+14) \simeq 0.505229$. This yields $\partial x_E^*/\partial \gamma \geq 0$ if $\gamma \leq (1/12)(3\sqrt{7}+14)$, but $\partial x_E^*/\partial \gamma < 0$ if $\gamma > (1/12)(3\sqrt{7}+14)$. From the numerator of $\partial x_L^*/\partial \gamma$, we find that $5 - 24\gamma + 45\gamma^2 > 0$ for all γ. Thus, $\partial x_L^*/\partial \gamma < 0$. ($ii$) The differentiation of (7) yields

$$\frac{\partial q_E^*}{\partial \gamma} = \frac{12(a-c)(-98 + 168\gamma + 171\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2}, \quad \frac{\partial q_L^*}{\partial \gamma} = -\frac{6(a-c)(112 - 840\gamma + 2061\gamma^2)}{(28 - 195\gamma + 216\gamma^2)^2}.$$

From the numerator of $\partial q_E^*/\partial \gamma$, $-98 + 168\gamma + 171\gamma^2 > 0$ for $\gamma > (7/57)(3\sqrt{6} - 4) \simeq 0.411216$. Thus, $\partial q_E^*/\partial \gamma > 0$. From the numerator of $\partial q_L^*/\partial \gamma$, we find that $112 - 840\gamma + 2061\gamma^2 = 0$ has no real root and a positive value. Thus, $\partial q_L^*/\partial \gamma < 0$. The differentiation

of (9) yields

$$\frac{\partial \Pi_E^*}{\partial \gamma} = \frac{8(a-c)^2(6\gamma - 7)(196 - 903\gamma - 342\gamma^2 + 4374\gamma^3)}{(28 - 195\gamma + 216\gamma^2)^3},$$

$$\frac{\partial \Pi_L^*}{\partial \gamma} = -\frac{(a-c)^2(15\gamma - 4)(-5488 + 39648\gamma - 137277\gamma^2 + 138024\gamma^3)}{2(28 - 195\gamma + 216\gamma^2)^3}.$$

Solving $\partial \Pi_E^*/\partial \gamma \geq 0$, we obtain $196 - 903\gamma - 342\gamma^2 + 4374\gamma^3 \geq 0$ for all $\gamma \geq \gamma_2 \simeq -0.50553$. Thus, $\partial \Pi_E^*/\partial \gamma > 0$. Solving $\partial \Pi_L^*/\partial \gamma \leq 0$, we obtain $-5488 + 39648\gamma - 137277\gamma^2 + 138024\gamma^3 > 0$ for all $\gamma > \gamma_3 \simeq 0.64468$. Thus, $\partial \Pi_L^*/\partial \gamma < 0$. Q.E.D.

B. Deriving equilibrium values in Case 1

Third stage: The producer's profit in country i yields $q_{ii}(x_{ii}, x_{ji}, g) = (1/3)(a - c + g + 2x_{ii} - x_{ji})$ and $q_{ij}(x_{jj}, x_{ij}, g) = (1/3)(a - c - 2g - x_{jj} + 2x_{ij})$, where $i \neq j$.

Second stage: The maximization problem of the shipper is $\max_g (g/3)[2(a - c) - 4g - (x_{HH} + x_{FF}) + 2(x_{HF} + x_{FH})]$. This yields the following shipping fee in the second stage: $g(x_{HH}, x_{HF}, x_{FF}, x_{FH}) = (1/8)[2(a - c) - (x_{HH} + x_{FF}) + 2(x_{HF} + x_{FH})]$.

First stage: Note that Π_i is divided into two parts: domestic supply Π_{ii} and export Π_{ij}. From the results of the second stage, we obtain the following:

$$\Pi_{ii}(x_{ii}, x_{ij}, x_{ji}, x_{jj}) = \frac{[10(a-c) - x_{jj} - 6x_{ji} + 15x_{ii} + 2x_{ij}]^2 - 288\gamma(x_{ii})^2}{576},$$

$$\Pi_{ij}(x_{ii}, x_{ij}, x_{ji}, x_{jj}) = \frac{[2(a-c) - 3x_{jj} - 2x_{ji} + 6x_{ij} + x_{ii}]^2 - 72\gamma(x_{ij})^2}{144}.$$

From the above equations, FOCs are as follows: $\partial \Pi_{ii}/\partial x_{ii} = 0 \Leftrightarrow (5/96)[10(a - c) - x_{jj} - 6x_{ji} + 2x_{ij} + 15x_{ii}] - \gamma x_{ii} = 0$ and $\partial \Pi_{ij}/\partial x_{ij} = 0 \Leftrightarrow 2(a-c) - 3x_{jj} - 2x_{ji} + 6x_{ij} + x_{ii} - 12\gamma x_{ij} = 0.$[23] From these equations, we obtain (12).

C. Deriving equilibrium values in Case 2

Third stage: The producer's profit in country i yields $q_{ii}(x_i, x_j, g) = (1/3)(a - c + g + 2x_i - x_j)$ and $q_{ij}(x_i, x_j, g) = (1/3)(a - c - 2g + 2x_i - x_j)$, where $i \neq j$.

---

[23]The SOCs for profit maximization are satisfied when the following conditions hold: $\partial^2 \Pi_{ii}/\partial x_{ii}^2 < 0$ is equivalent to $\gamma > 450/576 \simeq 0.78125$ and $\partial^2 \Pi_{ij}/\partial x_{ij}^2 < 0$ is equivalent to $\gamma > 1/2$.

Second stage: The maximization problem of the shipper is $\max_g (g/3)[2(a-c) - 4g + x_H + x_F]$. This yields $g(x_H, x_F) = (1/8)[2(a-c) + x_H + x_F]$.

First stage: From the results of the second stage, we obtain the following FOC for the profit maximization of the producers: $(1/288)[226(a-c) + (485 - 288\gamma)x_i - 259x_j] = 0$.[24] From this, we obtain (14).

D. The effects of γ on equilibrium values

Case 1: The differentiation of (12) yields

$$\frac{\partial q_{ii}^D}{\partial \gamma} = -\frac{4(a-c)(20 - 100\gamma + 159\gamma^2)}{(10 - 51\gamma + 48\gamma^2)^2} < 0; \quad \frac{\partial q_{ij}^D}{\partial \gamma} = \frac{4(a-c)(-25 + 40\gamma + 18\gamma^2)}{(10 - 51\gamma + 48\gamma^2)^2} > 0,$$

$$\frac{\partial x_{ii}^D}{\partial \gamma} = -\frac{20(a-c)(13 - 48\gamma + 60\gamma^2)}{(10 - 51\gamma + 48\gamma^2)^2} < 0; \quad \frac{\partial g^D}{\partial \gamma} = \frac{6(a-c)(-25 + 40\gamma + 18\gamma^2)}{(10 - 51\gamma + 48\gamma^2)^2} > 0,$$

$$\frac{\partial \overline{\pi}_S^D}{\partial \gamma} = \frac{48(a-c)^2\gamma(125 - 300\gamma + 70\gamma^2 + 72\gamma^3)}{(10 - 51\gamma + 48\gamma^2)^3} > 0,$$

$$\frac{\partial \Pi_i^D}{\partial \gamma} = -\frac{(a-c)^2(2000 - 9560\gamma + 20670\gamma^2 - 26371\gamma^3 + 15504\gamma^4)}{2(10 - 51\gamma + 48\gamma^2)^3} < 0.$$

Case 2: The differentiation of (14) yields

$$\frac{\partial q_{ii}^C}{\partial \gamma} = -\frac{6780(a-c)}{(144\gamma - 113)^2} < 0; \quad \frac{\partial q_{ij}^C}{\partial \gamma} = -\frac{2712(a-c)}{(144\gamma - 113)^2} < 0; \quad \frac{\partial x_i^C}{\partial \gamma} = -\frac{16272(a-c)}{(144\gamma - 113)^2} < 0,$$

$$\frac{\partial g^C}{\partial \gamma} = -\frac{4068(a-c)}{(144\gamma - 113)^2} < 0; \quad \frac{\partial \overline{\pi}_S^C}{\partial \gamma} = -\frac{390528(a-c)\gamma}{(144\gamma - 113)^3} < 0.$$

References

[1] Anderson, J.E., Wincoop, E., 2004. Trade costs. Journal of Economic Literature 42, 691-751.

[2] Banerjee, S., Lin, P., 2003. Downstream R&D, raising rivals' costs, and input price contracts. International Journal of Industrial Organization 21, 79-96.

[3] Behrens, K., Picard, P.M., 2011. Transportation, freight rates, and economic geography. Journal of International Economics 85, 280-291.

---

[24]The SOC is $\gamma > 288/485 \simeq 0.593814$.

[4] Brander, J.A., Krugman, P.R., 1983. A 'reciprocal dumping' model of international trade. Journal of International Economics 15, 313-321.

[5] Calabuig, V., Gonzalez-Maestre, M., 2002. Union structure and incentives for innovation. European Journal of Political Economy 18, 177-192.

[6] Clark, X., Dollar, D., Micco, A., 2004. Port efficiency, maritime transport costs, and bilateral trade. Journal of Developmant Economics 75, 417-450.

[7] Dewit, G., Leahy, D., 2004. Rivalry in uncertain export markets: commitment versus flexibility. Journal of International Economics 64, 195-209.

[8] Francois, J., Wooton, I., 2001. Trade in international transport services: the role of competition. Review of International Economics 9, 249-261.

[9] Haaland, J.I., Kind, H.J., 2008. R&D policies, trade and process innovation. Journal of International Economics 74, 170-187.

[10] Haucap, J., Wey, C., 2004. Unionization structure and innovation incentives. Economic Journal 114, 149-165.

[11] Hummels, D., 2007. Transportation costs and international trade in the second era of globalization. Journal of Economic Perspectives 21, 131-154.

[12] Hummels, D., Skiba, A., 2004. Shipping good apples out? an empirical confirmation of the Alchian-Allen conjecture. Journal of Political Economy 112, 1384-1402.

[13] Hummels, D., Lugovsky, V., Skiba, A., 2009. The trade reducing effects of market power in international shipping. Journal of Development Economics 89, 84-97.

[14] Ishii, A., 2004. Cooperative R&D between vertically related firms with spillovers. International Journal of Industrial Organization 22, 1213-1235.

[15] Kleinert, J., Spies, J., 2011. Endogenous transport costs in international trade. IAW Discussion Papers No. 74.

[16] Kujal, P., Ruiz, J., 2007. Cost effectiveness of R&D and strategic trade policy. B.E. Journal of Economic Analysis and Policy (Topics) 7, Article 21.

[17] Kujal, P., Ruiz, J., 2009. International trade policy towards monopoly and oligopoly. Review of International Economics 17, 461-475.

[18] Leahy, D., Neary, J.P., 1996. International R&D rivalry and industrial strategy without government commitment. Review of International Economics 4, 322-338.

[19] Leahy, D., Neary, J.P., 1999. R&D spillovers and the case for industrial policy in an open economy. Oxford Economic Papers 51, 40-59.

[20] Manasakis, C., Petrakis, E., 2009. Union structure and firms' incentives for cooperative R&D investments. Canadian Journal of Economics 42, 665-693.

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

[22] Matsushima, N., Takauchi, K., 2012. Port privatization in an international oligopoly. Unpublished manuscript.

[23] Mukherjee, A., Broll, U., Mukherjee, S., 2008. Licensing by a monopolist and unionized labor market. Journal of Economics 93, 59-79.

[24] Mukherjee, A., Pennings, E., 2011. Unionization structure, licensing and innovation. International Journal of Industrial Organization 29, 232-241.

[25] Mukherjee, A., Ray, A., 2007. Strategic outsourcing and R&D in a vertical structure. Manchester School 75, 297-310.

[26] Motta, M., 2004. Competition policy: theory and practice. Cambridge University Press, Cambridge.

[27] Qiu, L.D., Tao, Z., 1998. Policy on international R&D cooperation: subsidy or tax? European Economic Review 42, 1727-1750.

[28] Spencer, B.J., Brander, J.A., 1983. International R&D rivalry and industrial strategy. Review of Economic Studies 50, 707-722.

[29] Takauchi, K., 2011. Rules of origin and international R&D rivalry. Economics Bulletin 31, 2319-2332.

[30] Takauchi, K., 2012. International R&D rivalry with a shipping firm. MPRA Working Paper No. 36843.

[31] Yasar, M., Nelson, C.H., Rejesus, R.M., 2006. The dynamics of exports and productivity at the plant level: a panel data error correction model (ECM) approach. In: Baltagi, B.H. (Eds.). Panel Data Econometrics, Vol. 274: Theoretical Contributions and Empirical Application. Elsevier Science Ltd., 279-306.
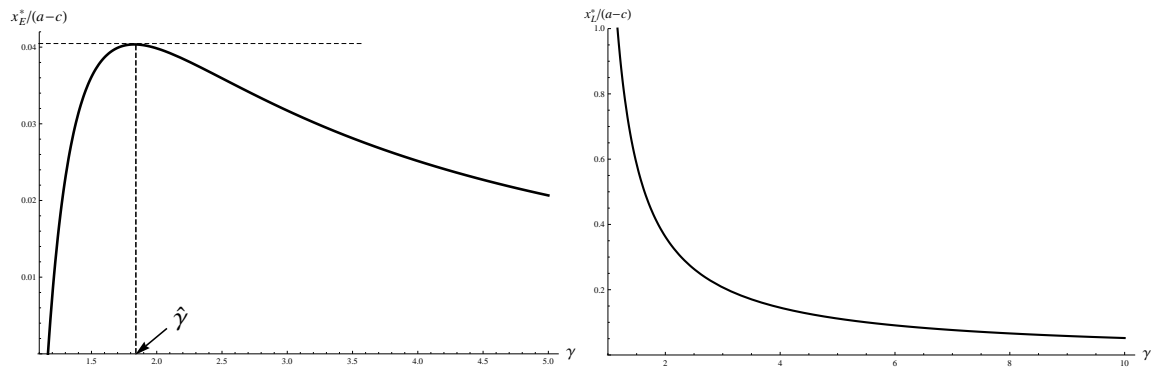
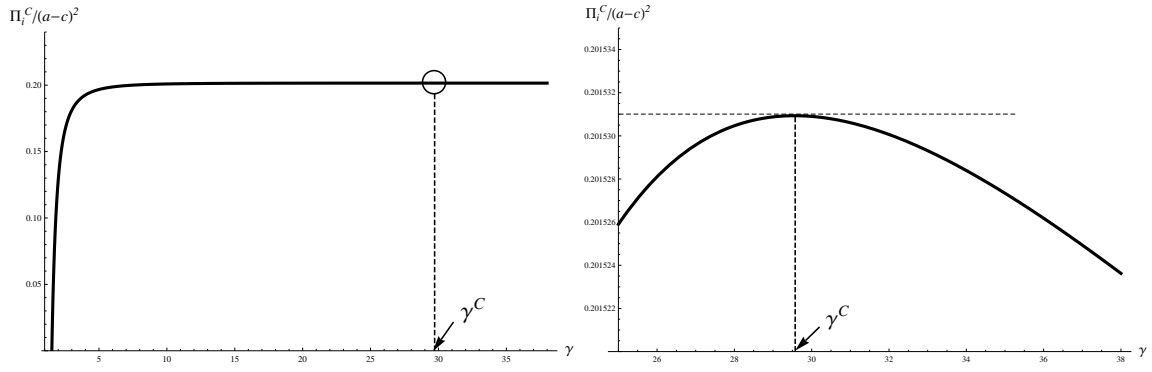Panel (a): Graph of x_E^* Panel (b): Graph of x_L^*

Figure 1: Equilibrium investment level of producers.
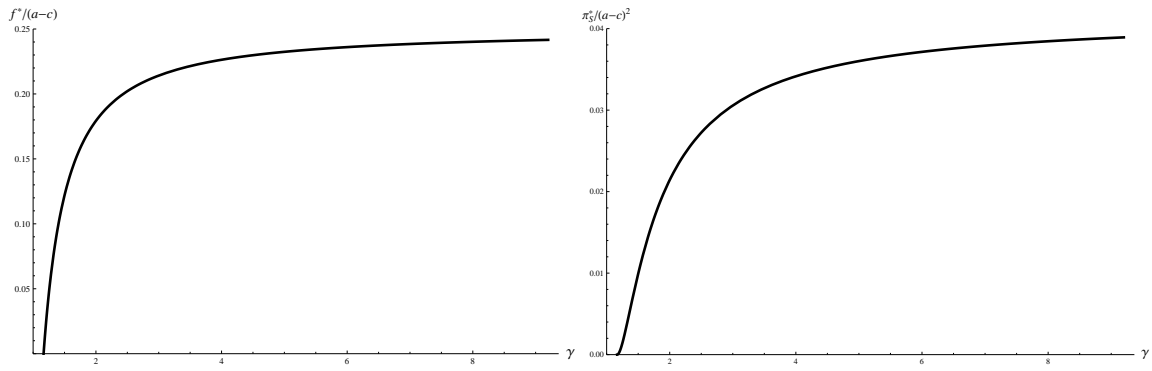
Panel (a): Graph of f^* Panel (b): Graph of π_S^*

Figure 2: Equilibrium shipping fee and profit of the shipper.

Panel (a): Graph of Π_i^C
$(12769/8352 < \gamma < 38)$.

Panel (b): Graph of Π_i^C $(25 < \gamma < 38)$.

Figure 3: Equilibrium profit of the producers in two-way trade (Case 2).