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**Tariffs and Technology Transfer through an Intermediate  
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# Tariffs and Technology Transfer through an Intermediate Product\*

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## Abstract

We examine the relationship between tariffs and technology transfer from the North to the South in an oligopolistic model. Technology is embodied in a key component which only the North firm can produce. Interestingly, a decrease in the tariff on the final good as well as an increase may induce technology transfer. If the South subsidizes the final-good production or imports of the intermediate good, technology transfer is also facilitated. However, the welfare effects are different between tariffs and subsidies. Our analysis suggests that the South should take pro-competitive policies to induce technology transfer and enhance welfare.

*Keywords:* technology transfer, intermediate products, tariffs, licensing, North-South trade

*JEL Classification:* F12, F21, F23

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# 1 Introduction

Technology transfer from developed countries (the North) to developing countries (the South) has received extensive attention in the international trade literature. The essence of technology is often embodied in sophisticated intermediate products which the South is unable to produce.<sup>1</sup> In this case, even if know-how to produce final products is known to the South, they cannot produce those final products by themselves. To produce the final products, they have to import such key inputs from the North. For example, when Hyundai Motor Co. (a Korean auto maker) manufactured the first Korean car in 1975, the engine was provided by Mitsubishi Motors Co. (a Japanese auto maker), which transferred its technology to Hyundai.<sup>2</sup>

The North-South technology transfer through trade in intermediate products differs from licensing, which is a typical channel of technology transfer, in the important way. The South governments often demand technology transfer without any payments for licensing. Even if licensing opportunities are present, the South governments sometimes impose various regulations such as a cap on royalty rates.<sup>3</sup> Moreover, intellectual property rights are often not well enforced in the South. Under such circumstances, licensing is likely to be discouraged. However, it is not necessarily the case for technology transfer embodied in intermediate products, because the North benefits from selling intermediate products and the South may not be able to imitate them.

We consider the North-South technology transfer through trade in intermediate products. Building a simple oligopolistic model, we specifically examine the relationship between tariffs and technology transfer. The relationship between tariffs and foreign direct investment (FDI) has been explored extensively in the existing literature.<sup>4</sup> A well-known relationship is tariff-jumping FDI, that is, higher tariffs induce exporting firms to undertake FDI. However, there have been few theoretical studies (except for those mentioned below) to investigate the relationship between tariffs and technology transfer.

As in the case of FDI, an increase in the tariff on the final good leads to “tariff-jumping” technology transfer in our model. The North firm, which exports the final good to the South, loses as the South tariff rises. In order to offset the loss, it may have incentive to provide a potential local entrant (i.e., a South firm) with its technology by selling an essential intermediate product. Interestingly, a tariff-reduction may also induce technology transfer. When the tariff is lowered, other North firms may enter the South market, which is harmful to the incumbent North firm. To discourage such entry, the incumbent North firm may transfer its technology to a potential local entrant. Although the South firm enters the market and becomes a competitor for the incumbent North firm, the loss is smaller because it can benefit from the sales of the

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<sup>1</sup>Coe et al. (1977) point out that between 1971 and 1977, R&D in the North increased total factor productivity in the South through their imports of intermediate products and capital goods from the North.

<sup>2</sup>Similar examples include a Malaysian auto maker, Proton, established in 1983 and another Korean auto maker, Samsung Motors, established in 1994. Mitsubishi Motors Co. and Nissan Motor Co., Ltd., respectively, provided Proton and Samsung with technological assistance. Samsung initially imported even nuts and bolts from Japan.

<sup>3</sup>For example, see Davies (1977) for the Indian case and Peck and Tamura (1976) for the Japanese case.

<sup>4</sup>See Markusen (2002) and Barba Navaretti and Venables (2004), among others.

intermediate product to the South firm. That is, the incumbent North firm may strategically generate “entry-detering” technology transfer. Thus, a tariff-reduction as well as a tariff-increase may induce technology transfer.

We should mention that tariffs are not necessary for the entry-detering technology transfer. Any policy which encourages entry could result in technology transfer. This contrasts with a conventional policy inducing technology transfer through FDI. It has been observed that the South government guarantees a North firm market power in return of technology transfer under an obligation to form a joint venture (JV) with a South firm.<sup>5</sup> Our analysis suggests that pro-competitive policy inducing more entry should work without forcing North firms to transfer technology. Moreover, in our analysis, FDI is not indispensable for technology transfer.

Lin and Saggi (1999), Pack and Saggi (2001) and Ishikawa and Horiuchi (2007) also consider strategic uses of the North-South technology transfer.<sup>6</sup> In particular, Lin and Saggi (1999) show in a dynamic North-South model that FDI makes the South firm’s imitation of an advanced technology easier and intensifies competition in the South market and hence FDI undertaken by one of the North firms may delay the other North firm’s switch from exports to FDI. However, their primary purpose is to show a paradoxical result that technology spillover to local firms through FDI may facilitate FDI rather than discourage it.

Kabiraj and Marjit (2003) and Mukherjee and Pennings (2006) point out the possibility of “tariff-induced” technology transfer through licensing. Using a duopoly model, Kabiraj and Marjit (2003) show that the foreign firm has incentive to license its superior technology to the domestic rival only if the initial cost-difference between the foreign and domestic firms is small. By reducing the cost-difference, a tariff may induce licensing. Mukherjee and Pennings (2006) consider the relationship between licensing by the foreign monopolist to potential entrants and the timing of the imposition of the (optimal) tariff. Although our analysis is related to theirs, our focus is quite different from theirs. We consider tariff-reductions as well as tariff-hikes. In particular, we show that from the welfare point of view, technology transfer induced by tariff-reductions is better than that by tariff-hikes.

We should mention that in our model, we can simply reinterpret the sale of an intermediate product as the licensing with per-unit royalty without changing the main results. Thus, our analysis is also related to patent licensing in the industrial organization literature. For instance, Rockett (1990) examines to whom technology should be licensed in a closed economy. She particularly points out that a patentee-monopolist may have incentive to license its technology to a weak entrant to deter a strong entrant from entering market. Eswaran (1994) generalizes Rock-

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<sup>5</sup>For example, the Chinese government does not allow foreign auto makers to have their own subsidiaries in China. They force foreign auto makers to form JVs with local firms in order to accelerate technology transfer. In addition, foreign auto makers have to obtain Chinese government’s permission to form JVs, which is fairly restrictive.

<sup>6</sup>Pack and Saggi (2001) are concerned with technology transfer from the downstream sector to the upstream sector through outsourcing. Ishikawa and Horiuchi (2007) show Pareto gains from technology spillover through FDI in vertically related markets.

ett's (1990) analysis.<sup>7</sup> However, both of these studies assume licensing with two-part tariffs (i.e. a fixed fee plus per-unit royalty);<sup>8</sup> besides they do not consider welfare implications. More importantly, their main concerns are about the industrial or market structures under the possibility of licensing, while ours are rather about the North-South technology transfer through trade in an intermediate good and its policy implications.

The rest of the paper is organized as follows. Section 2 presents the basic model. Section 3 investigates the effects of an increase in the tariff on the final good on technology transfer, while section 4 examines those of a decrease in the tariff. Section 5 analyzes economic welfare. Section 6 explores the effects of subsidies on technology transfer and compare them with the effects of tariffs on the final good. Section 7 discusses some alternative assumptions. Section 8 concludes the paper.

## 2 The Basic Model

There are two countries, the North and the South. We consider the interactions among an incumbent, a North firm (firm  $N_1$ ), and two potential entrants, a North firm (firm  $N_2$ ) and a South firm (firm  $S$ ), in the South market. Firms produce homogenous final goods. Firms  $N_1$  and  $N_2$  export their final goods to the South.<sup>9</sup> Firm  $N_2$  has to incur fixed costs (FCs),  $f_2$ , to serve the South market. To start production, firm  $S$  needs to have the technology transferred from firm  $N_1$ , that is, firm  $S$  has to purchase a key intermediate good from firm  $N_1$ . Firm  $N_2$  does not supply its intermediate good to firm  $S$ .<sup>10</sup> If more than two firms serve the South market, they compete in quantities with Cournot conjectures. The inverse demand is given by the following linear function:<sup>11</sup>

$$p(X) = b - aX,$$

where  $p$  and  $X$  are, respectively, the price and the demand of the final good.  $a$  and  $b$  are parameters.

One unit of the intermediate good is required for each unit of the final good. In the North, the marginal cost (MC) to produce the intermediate product is normalized to be zero. Firm  $N_1$  sells firm  $S$  its intermediate good at price  $r$ . The MC to produce the final product from the intermediate good is  $c^N$  in the North and  $c^S$  in the South. Even if the technology is transferred, firm  $N_1$  is more efficient in the final-good production than firm  $S$ . Specifically,  $c^N < c^S$  as well as  $b > c^N + t$  which are necessary for our benchmark case (i.e., the monopoly by firm  $N_1$ ) to exist in

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<sup>7</sup>Eswaran (1994) shows that in the presence of a potential entrant, an incumbent may invite outsiders as licensees.

<sup>8</sup>The licensing literature has extensively compared between per-unit royalty and fixed fee. See, for example, Wang (1998) and Kamien and Tauman (2002).

<sup>9</sup>We assume away FDI by the North firms. Firms refrain from FDI in the presence of high setup costs of FDI and high risk of expropriation, for example.

<sup>10</sup>For example, this could be the case if firm  $N_2$  has to incur large FCs to export the intermediate good. See also Section 7.

<sup>11</sup>Even if the demand function is non-linear, the essence of our results would not change.

the following analysis. For example,  $c^N < c^S$  reflects the managerial inefficiency of firm  $S$ . The South government imposes a specific tariff,  $t$ , on the final good and no tariff on the intermediate good. The profits of firms  $N_1$ ,  $N_2$ , and  $S$  are, respectively, given by

$$\begin{aligned}\pi^{N_1} &= \pi^{N_1f} + \pi^{N_1m} = [p - (c^N + t)]x^{N_1} + rx^S, \\ \pi^{N_2} &= \pi^{N_2f} = [p - (c^N + t)]x^{N_2} - f_2, \\ \pi^S &= [p - (c^S + r)]x^S,\end{aligned}$$

where  $x^i$  ( $i = N_1, N_2, S$ ) is the output of firm  $i$ ; and  $\pi^{N_1f}$  and  $\pi^{N_1m}$  are, respectively, the profits from the final-good market and the intermediate-good market.

The model involves four stages of decision. In stage 0, the South government determines the tariff rate. In stage 1, firm  $N_1$  decides whether to export the intermediate good to firm  $S$  and whether to serve the final-good market. If it decides to export the intermediate good, firm  $N_1$  determines the intermediate-good price and makes a take-it-or-leave-it offer to firm  $S$ , which in turn decides whether to accept it. In stage 2, firm  $N_2$  decides whether to enter the market. In stage 3, the firms compete in the final-good market. The game is solved by backward induction.

There are seven possible equilibria in stage 3: a monopoly by firm  $N_1$ , or  $S$ , or  $N_2$ ; a duopoly between firms  $N_1$  and  $S$ , or between  $N_1$  and  $N_2$ , or between  $S$  and  $N_2$ ; and an oligopoly among three firms  $N_1$ ,  $N_2$  and  $S$ . However, firm  $N_2$  cannot be a monopolist in equilibrium. Moreover, the duopoly between firms  $S$  and  $N_2$  does not arise in equilibrium, because firm  $N_1$  never has incentive to switch the market structure from the duopoly between firms  $N_1$  and  $S$  to the duopoly between firms  $S$  and  $N_2$ .

### 3 The Effects of Tariff-hikes

This section analyzes the effects of tariff-hikes on technology transfer. In our analysis, the benchmark is the monopoly by firm  $N_1$  (henceforth the  $N$  monopoly) under a non-negative tariff.<sup>12</sup> That is, firm  $N_1$  initially monopolizes the market. Then the equilibrium is given by<sup>13</sup>

$$x_{N_1}^{N_1}(t) = \frac{b - c^N - t}{2a} > 0, \quad (1)$$

$$p_N(t) = \frac{b + c^N + t}{2}, \quad (2)$$

$$\pi_{N_1}^{N_1}(t) = \frac{(b - c^N - t)^2}{4a}. \quad (3)$$

An increase in  $t$  makes the potential profits of firm  $N_2$  lower and hence does not induce firm  $N_2$ 's entry. Thus, the possible equilibria are the  $N$  monopoly, the duopoly between firms  $N_1$  and  $S$  (henceforth the  $NS$  duopoly), and the monopoly by firm  $S$  (henceforth the  $S$  monopoly).

<sup>12</sup>The tariff rates under which the monopoly by firm  $N_1$  is actually the initial equilibrium will be set out later.

<sup>13</sup>Subscripts stand for the final-good market structure:  $N$  ( $S$ ) is the monopoly by firm  $N_1$  ( $S$ );  $NS$  ( $NN$ ) is the duopoly between firms  $N_1$  and  $S$  ( $N_1$  and  $N_2$ ); and  $NSN$  is the oligopoly among three firms.

In the last stage, the  $NS$  duopoly equilibrium is given by<sup>14</sup>

$$x_{NS}^{N_1}(r, t) = \frac{b + (r + c^S) - 2(c^N + t)}{3a}, x_{NS}^S(r, t) = \frac{b + (c^N + t) - 2(r + c^S)}{3a}, \quad (4)$$

$$p_{NS}(r, t) = \frac{b + (r + c^S) + (c^N + t)}{3}, \quad (5)$$

$$\pi_{NS}^{N_1}(r, t) = \frac{[b + (r + c^S) - 2(c^N + t)]^2}{9a} + r \frac{b + (c^N + t) - 2(r + c^S)}{3a}, \quad (6)$$

$$\pi_{NS}^S(r, t) = \frac{[b + (c^N + t) - 2(r + c^S)]^2}{9a}, \quad (7)$$

and the  $S$  monopoly equilibrium is

$$x_S^S(r) = \frac{b - (r + c^S)}{2a}, \quad (8)$$

$$p_S(r) = \frac{b + r + c^S}{2}, \quad (9)$$

$$\pi_S^{N_1}(r) = r \frac{b - (r + c^S)}{2a}, \quad (10)$$

$$\pi_S^S(r) = \frac{[b - (r + c^S)]^2}{4a}. \quad (11)$$

In stage 1, given  $t$ , firm  $N_1$  can choose the most preferable market structure through technology transfer. Obviously, the technology is not transferred under the  $N$  monopoly. Under the  $NS$  duopoly, firm  $N_1$  determines  $r$  so as to maximize the profits  $\pi_{NS}^{N_1}$  subject to  $\pi_{NS}^S > 0$  and  $\pi_{NS}^{N_1f} > 0$  (i.e.,  $x_{NS}^S > 0$  and  $x_{NS}^{N_1} > 0$ ). We check under what condition  $x_{NS}^S > 0$  and  $x_{NS}^{N_1} > 0$  hold. In view of (4), the constraints are equivalent to<sup>15</sup>

$$2(c^N + t) - (b + c^S) \equiv \tilde{r}_{NS} < r < \bar{r}_{NS} \equiv \frac{b + c^N + t - 2c^S}{2}.$$

On the other hand,  $r$  that maximizes  $\pi_{NS}^{N_1}$  without any constraint is given by

$$r_{NS} \equiv \frac{5b - (c^N + t + 4c^S)}{10}. \quad (12)$$

We can easily verify that  $\tilde{r}_{NS} < r_{NS} < \bar{r}_{NS}$  holds if and only if

$$c^S - c^N \equiv t_{NS} < t < \tilde{t} \equiv \frac{5b + 2c^S - 7c^N}{7}. \quad (13)$$

When  $\tilde{r}_{NS} < r_{NS} < \bar{r}_{NS}$ , we can obtain the duopoly equilibrium by substituting  $r_{NS}$  into (4)-(7):

$$x_{NS}^{N_1}(t) = \frac{5b - 7(c^N + t) + 2c^S}{10a}, x_{NS}^S(t) = \frac{4(c^N + t - c^S)}{10a}, \quad (14)$$

$$p_{NS}(t) = \frac{5b + 3(c^N + t) + 2c^S}{10}, \quad (15)$$

$$\pi_{NS}^{N_1}(t) = \frac{5[b - (c^N + t)]^2 + 4(c^N + t - c^S)^2}{20a}, \quad (16)$$

$$\pi_{NS}^S(t) = \frac{4(c^N + t - c^S)^2}{25a}. \quad (17)$$

<sup>14</sup>The general form of equilibrium in the last stage is given in the appendix (equations (A1)-(A7)).

<sup>15</sup> $\tilde{r}_{NS} < \bar{r}_{NS}$  holds with  $b - c^N - t > 0$ .

When  $t$  becomes high enough, firm  $N_1$  exits from the final-good market and exports only the intermediate good whose price is determined so as to maximize  $\pi_S^{N_1}$ . It is straightforward to show such  $r$  is given by

$$r_S = \frac{b - c^S}{2} \quad (18)$$

and hence the equilibrium is given by

$$x_S^S = \frac{b - c^S}{4a}, \quad (19)$$

$$p_S = \frac{3b + c^S}{4}, \quad (20)$$

$$\pi_S^{N_1} = \frac{(b - c^S)^2}{8a}, \quad (21)$$

$$\pi_S^S = \frac{(b - c^S)^2}{16a}. \quad (22)$$

We are now ready to pin down the market structures. First, we can easily verify  $\pi_N^{N_1} = \pi_{NS}^{N_1}$  at  $t_{NS}$ . Thus, firm  $N_1$  starts exporting the intermediate good once  $t = t_{NS}$  holds. We next derive the tariff rate,  $t_S$ , under which firm  $N_1$  stops serving the final-good market. From  $\pi_{NS}^{N_1} = \pi_S^{N_1}$ , we obtain

$$t_S = (c^S - c^N) + \frac{(b - c^S)(10 - \sqrt{10})}{18}.$$

It should be noted that  $t_S$  is less than  $\tilde{t}$  and hence  $x_{NS}^{N_1} > 0$  at  $t_S$ . Even if  $x_{NS}^{N_1} > 0$ , it is profitable for firm  $N_1$  to stop serving the final-good market. Moreover,  $t_S$  is greater than  $t_{NS}$  and hence the final-good market structure never directly shifts from the firm  $N_1$ 's monopoly to the firm  $S$ 's monopoly.

The above analysis establishes the following proposition.

**Proposition 1** *Suppose firm  $N_1$  initially monopolizes the South final-good market. Then both firms  $N_1$  and  $S$  serve the South final-good market if  $t_{NS} < t < t_S$ , while firm  $S$  monopolizes the market if  $t \geq t_S$ . Thus, an increase in the tariff on the final good induces technology transfer from firm  $N_1$  to firm  $S$ .*

The intuition for technology transfer is straightforward. As the tariff increases, the profits of firm  $N_1$  decrease. In order to offset the loss, it transfers its technology to a potential local entrant by selling the essential intermediate product, which generates profits for firm  $N_1$ . That is, an increase in the tariff on the final good causes the tariff-jumping technology transfer.

## 4 The Effects of Tariff-reductions

In this section, we examine a decrease in the tariff. As in the last section, the benchmark is the  $N$  monopoly with a non-negative tariff. This is, the tariff rate under the benchmark,  $t_0$ , satisfies  $0 \leq t_0 \leq t_{NS}$ . To make the following analysis meaningful, we assume

$$c^N \leq b - 3\sqrt{af_2} \leq c^S, \text{ i.e., } \frac{(b - c^S)^2}{9a} \leq f_2 \leq \frac{(b - c^N)^2}{9a}. \quad (23)$$



As we see below, under this assumption, the market structure actually changes from the monopoly as  $t$  falls.<sup>16</sup> In the following, we investigate how the market structure shifts.

In the absence of firm  $N_2$ , a decrease in  $t$  never results in technology transfer. When  $t$  becomes low enough for firm  $N_2$  to cover its FC, however, firm  $N_2$  starts exporting to the South. For firm  $N_1$ , the duopoly between firms  $N_1$  and  $S$  (henceforth the  $SN$  duopoly) is preferable to the duopoly between firms  $N_1$  and  $N_2$  (henceforth the  $NN$  duopoly), because not only firm  $N_1$  gains from selling the intermediate good to firm  $S$  but also firm  $S$  is less efficient than firm  $N_2$ . Thus, firm  $N_1$  lets firm  $S$  enter just before firm  $N_2$  enters. This implies that the price of the intermediate good set by firm  $N_1$  is lower than the monopoly price so as to cause firm  $S$ 's entry. Firm  $N_1$  strategically transfers its technology to firm  $S$  to deter firm  $N_2$  from entering the market.

We let  $t_N$  denote the tariff rate at which the profits of firm  $N_2$  under a duopoly between firms  $N_1$  and  $N_2$  are zero, that is, firm  $N_2$  enters the market in the absence of firm  $S$  if the tariff rate is lower than  $t_N$ . Under the  $NN$  duopoly, the following holds

$$\pi_{NN}^{N_2}(t) = \frac{1}{a} \left( \frac{b - c^N - t}{3} \right)^2 - f_2. \quad (24)$$

Thus, firm  $N_1$  starts exporting the intermediate good to firm  $S$  at the tariff rate which satisfies  $\pi_{NN}^{N_2}(t) = 0$ , i.e.,

$$t_N = b - c^N - 3\sqrt{af_2}. \quad (25)$$

In view of (23),  $t_N \geq 0$ . Since firm  $N_1$  initially monopolizes the market, we implicitly assume that the initial tariff is between  $t_N$  and  $t_{NS}$ . It should be noted that  $t_N < t_{NS} (\equiv c^S - c^N)$  holds, because of (23).

Once  $t$  lowers to the level of  $t_N$ , firm  $N_1$  transfers its technology to firm  $S$  to deter firm  $N_2$ 's entry and hence the  $SN$  duopoly prevails. The price of the intermediate good charged by firm  $N_1$  is derived as follows. When three firms compete in the market, the profits of firm  $N_2$  are given by

$$\pi_{NSN}^{N_2}(r, t) = \frac{[b - 2(c^N + t) + (r + c^S)]^2}{16a} - f_2.$$

Firm  $N_1$  sets  $r$  such that firm  $S$  enters the market and  $\pi_{NSN}^{N_2} = 0$ , that is,<sup>17</sup>

$$r_{SN} = 2t + 4\sqrt{af_2} + 2c^N - c^S - b. \quad (26)$$

<sup>16</sup>A decrease in the tariff may lead to a negative tariff (i.e., an import subsidy), which we allow in our analysis.

<sup>17</sup>We use subscripts  $SN$  to distinguish the duopoly obtained by reducing the tariff from that brought by raising the tariff.

Substituting  $r_{SN}$  into (4)-(7), we can obtain the duopoly equilibrium

$$x_{SN}^{N_1}(t) = \frac{4\sqrt{f_2}}{3\sqrt{a}}, x_{SN}^S(t) = \frac{3b - 3(c^N + t) - 8\sqrt{af_2}}{3a}, \quad (27)$$

$$p_{SN}(t) = \frac{3(c^N + t) + 4\sqrt{af_2}}{3}, \quad (28)$$

$$\pi_{SN}^{N_1}(t) = \frac{[2t + 4\sqrt{af_2} + 2c^N - c^S - b][3b - 3(c^N + t) - 8\sqrt{af_2}]}{3a} + \frac{16f_2}{9}, \quad (29)$$

$$\pi_{SN}^S(t) = \frac{[3b - 3(c^N + t) - 8\sqrt{af_2}]^2}{9a}. \quad (30)$$

As  $t$  falls, firm  $N_1$  has to decrease  $r_{SN}$  to deter firm  $N_2$ 's entry. When  $r$  becomes low enough, firm  $N_1$  may lose incentive for such entry deterrence. If this is the case, there are two possibilities. One is to let firm  $N_2$  simply enter the market and the other is to let firm  $N_2$  enter the market but let firm  $S$  exit from the market. Firm  $N_1$  compares the profits under the oligopoly among three firms (henceforth the  $NSN$  oligopoly) with those under the  $NN$  duopoly. If the latter are greater than the former, firm  $N_1$  stops providing firm  $S$  with the intermediate good and firm  $S$  is forced to exit from the market, that is, the foreclosure happens. If the latter is less than the former, on the other hand, the  $NSN$  oligopoly prevails.

The equilibrium under the  $NN$  duopoly is given by

$$x_{NN}^{N_1}(t) = x_{NN}^{N_2}(t) = \frac{b - c^N - t}{3a}, \quad (31)$$

$$p_{NN}(t) = \frac{b + 2(c^N + t)}{3}, \quad (32)$$

$$\pi_{NN}^{N_1}(t) = \frac{(b - c^N - t)^2}{9a}, \quad (33)$$

$$\pi_{NN}^{N_2}(t) = \frac{(b - c^N - t)^2}{9a} - f_2. \quad (34)$$

The critical level of  $t$  under which firm  $N_1$  is indifferent between the  $SN$  duopoly and the  $NN$  duopoly is given by

$$t_{SN} \equiv \frac{29b - 38c^N + 9c^S - 84\sqrt{af_2} - \sqrt{[9(b - c^S - \frac{52}{27}\sqrt{af_2})]^2 + \frac{6080}{9}af_2}}{38}. \quad (35)$$

The appendix shows the following lemma and hence only the  $NN$  duopoly arises under  $t < t_{SN}$ .

**Lemma 1** *An  $NSN$  oligopoly equilibrium arises only if  $t > t_{NSN} \equiv (-b + 9c^S - 8c^N)/8$ . However,  $t_{NSN} > t_{SN}$  holds with (23), and hence any  $NSN$  oligopoly equilibrium is not observed.*

Intuitively, firm  $N_1$  can still earn some profits by selling the intermediate good to firm  $S$  under the  $NSN$  oligopoly, but this is in exchange at the cost of the smaller profits in the final-good market. Since the latter negative effect dominates the former positive effect, firm  $N_1$  vertically forecloses.

The following should be noted. First,  $r_{SN} = 0$  may hold with  $t > t_{SN}$ . We let  $\bar{t}$  denote the tariff rate which results in  $r_{SN} = 0$ :

$$\bar{t} \equiv \frac{b + c^S - 2c^N - 4\sqrt{af_2}}{2}. \quad (36)$$

As shown in the proof of Lemma 1,  $\bar{t} > t_{SN}$  holds. Thus, we obtain<sup>18</sup>

**Lemma 2** *Firm  $N_1$  sells its intermediate good to firm  $S$  even below the MC in order to deter firm  $N_2$  from entering the market.*

Second, noting  $t_N \geq 0$ , we can easily verify  $t_{SN} < t_N$ . Therefore, when  $t$  falls, the market structure does not directly shift from the firm  $N_1$ 's monopoly to the  $NN$  duopoly. It is always beneficial for firm  $N_1$  to deter firm  $N_2$ 's entry unless  $t$  is too low.

The above analysis establishes the following proposition.

**Proposition 2** *Suppose that firm  $N_1$  initially monopolies the South final-good market. Firms  $N_1$  and  $S$  serve the South final-good market if  $t_{SN} \leq t < t_N$ , while firms  $N_1$  and  $N_2$  serve the market if  $t < t_{SN}$ . Thus, a decrease in the tariff on the final good induces technology transfer from firm  $N_1$  to firm  $S$ . However, if the decrease is large enough, technology transfer may not occur.*

In view of Propositions 1 and 2, the relationship between tariff rates and the market structures is summarized in Figure 1.

**Figure 1 around here**

## 5 Welfare Analysis

In this section, we analyze welfare in the South, measured by the sum of consumer surplus, profits and tariff revenue.

$$W \equiv U(X) - p(X)X + \pi^S + t(x^{N_1} + x^{N_2}), \quad (37)$$

where  $dU/dX = p$ . In particular, we examine the relationship between welfare and tariff rates and obtain the optimal tariff.

We first compare welfare under the  $S$  monopoly with that under the  $NS$  duopoly. When  $t \geq t_S$ , the market is monopolized by firm  $S$  and welfare is given by

$$W_S = \frac{3(b - c^S)^2}{32a}, \quad (38)$$

which is obviously independent of  $t$ . Welfare under the  $NS$  duopoly is given by the following quadratic function with respect to  $t$ :

$$W_{NS}(t) = \frac{32(c^N + t - c^S)^2 + [5b - 3(c^N + t) - 2c^S]^2 + 20t[5b - 7(c^N + t) + 2c^S]}{200a}, \quad (39)$$

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<sup>18</sup> $r < 0$  does not necessarily imply that the actual price of the intermediate good is negative, because the MC to produce the intermediate product is simply normalized to be zero.

which is convex. Without any constraint on  $t$ ,  $W_{NS}$  takes its maximum value

$$W_{NS}^* = \frac{49(c^N)^2 + 36(c^S)^2 - 50bc^N - 24bc^S - 48c^Nc^S + 37b^2}{198a} \quad (40)$$

at  $t = t_{NS}^* \equiv (35b - 29c^N - 6c^S)/99$ , which is less than  $t_S$  because  $t_S - t_{NS}^* = [(40 - 11\sqrt{10})(b - c^N) + (100 + 11\sqrt{10})(c^S - c^N)]/198 > 0$ . Since

$$W_{NS}(t_S) - W_S = \frac{(b - c^S)[(83 + 16\sqrt{10})(b - c^N) + (77 + 40\sqrt{10})(c^S - c^N)]}{1440a} > 0 \quad (41)$$

holds,  $W_{NS}^* > W_{NS}(t_S) > W_S$ . That is,

**Lemma 3** *The maximum welfare under the NS duopoly is greater than  $W_S$ .*

We next compare welfare under the NS duopoly with welfare under the N monopoly. When  $t_N \leq t \leq t_{NS}$ , the market is monopolized by firm  $N_1$  and welfare is given by

$$W_N(t) = \frac{(b - c^N + 3t)(b - c^N - t)}{8a}, \quad (42)$$

which is quadratic and convex. Without any constraint on  $t$ ,  $W_N$  takes its maximum value

$$W_N^* = \frac{(b - c^N)^2}{6a} \quad (43)$$

at  $t = t_N^* \equiv (b - c^N)/3$ .

Straightforward but tedious calculation reveals (i)  $W_N(t_{NS}) = W_{NS}(t_{NS})$ , (ii)  $t_{NS} < t_{NS}^*$  if and only if  $b + 2c^N - 3c^S > 0$ , (iii)  $t_S < t_N^*$  if and only if  $40b + 100c^S - 140c^N < 11\sqrt{10}(b - c^S)$ , and (iv)  $t_N^* < t_N$  if and only if  $2b - 2c^N - 9\sqrt{af_2} > 0$ , i.e.,  $f_2 < 4(b - c^N)^2/81a$ .

Therefore, if  $b + 2c^N - 3c^S > 0$ , the maximum welfare,  $\widehat{W}$ , is obtained under the NS duopoly. If  $b + 2c^N - 3c^S < 0$ , on the other hand, the maximum welfare is obtained under the N monopoly. In this case, we have  $\widehat{W} = W_N^*$  if  $t_N^* \geq t_N$  and  $\widehat{W} = W_N(t_N)$  if  $t_N^* < t_N$ .<sup>19</sup>

**Lemma 4** *The maximum welfare under the NS duopoly is greater than that under the N monopoly if and only if  $b + 2c^N - 3c^S > 0$ .*

The intuition of this lemma is as follows. We can rewrite the condition  $b + 2c^N - 3c^S > 0$  as  $b - c^N > 3(c^S - c^N)$ . The LHS is related to the market size, while the RHS is related to the difference in efficiency. This condition is likely to hold when the market is relatively large and/or firm  $S$  is not very inefficient relative to firm  $N_1$ . Consumer surplus is smaller under the NS duopoly than under the N monopoly.<sup>20</sup> However, when the market is relatively large and/or firm  $S$  is not very inefficient relative to firm  $N_1$ , the firm  $S$ 's profits are relatively large and an increase in the tariff is likely to raise the tariff revenue under the NS duopoly.

<sup>19</sup>  $t_N^* < t_N$ , i.e.,  $2b - 2c^N - 9\sqrt{af_2} > 0$  implies  $t_N^* < t_{NS}$ , i.e.,  $b + 2c^N - 3c^S < 0$ .

<sup>20</sup> The price of the final good monotonically rises as the tariff rises.  $p_N(t) = p_{NS}(t)$  holds at  $t_{NS}$ .

Welfare under the  $SN$  duopoly is

$$W_{SN}(t) = \frac{3 \left[ t - (b - c^N - \frac{8}{3}\sqrt{af_2}) \right]^2}{2a} + \frac{4\sqrt{af_2} (b - c^N - 2\sqrt{af_2})}{3a}, \quad (44)$$

which is quadratic and concave. Without any constraint on  $t$ ,  $W_{SN}$  takes the minimum value at  $t = \underline{t} \equiv (3b - 3c^N - 8\sqrt{af_2})/3$ . Since  $\underline{t} > t_N$ ,  $W_{SN}$  is decreasing for  $t \in [t_{SN}, t_N]$  and hence  $W_{SN}$  takes its maximum value at  $t = t_{SN}$ :

$$W_{SN}(t_{SN}) = \frac{1}{4332a} \left( \frac{(729(b - c^S)^2 + 8(371b - 722c^N + 351c^S)\sqrt{af_2})}{+\{81(b - c^S) - 156\sqrt{af_2}\}\sqrt{[9(b - c^S - \frac{52}{27}\sqrt{af_2})]^2 + \frac{6080}{9}af_2}} \right) \quad (45)$$

Welfare under the  $NN$  duopoly is

$$W_{NN}(t) = \frac{2(b - c^N - t)(b - c^N + 2t)}{9a}, \quad (46)$$

which is quadratic and convex. Without any constraint on  $t$ ,  $W_{NN}$  takes its maximum value

$$W_{NN}^* = \frac{(b - c^N)^2}{4a} \quad (47)$$

at  $t = t_{NN}^* \equiv (b - c^N)/4 > 0$ .

Tedious calculation leads to the following lemmas.

**Lemma 5** *Suppose  $b + 2c^N - 3c^S > 0$ . Then  $W_{NN}(t_{SN})$  is greater than the maximum welfare under the  $NS$  duopoly and either  $W_{NN}(t_{SN})$  or  $W_{SN}(t_{SN})$  is the global maximum.*

**Lemma 6** *Suppose  $b + 2c^N - 3c^S \leq 0$ . Then  $W_{NN}(t_{SN})$  is greater than the maximum welfare under the  $N$  monopoly. If the optimal tariff under the  $NN$  duopoly is the interior solution (i.e.,  $t_{NN}^* < t_{SN}$ ),  $W_{NN}(t_{NN}^*)$  is the the global maximum. If the optimal tariff under the  $NN$  duopoly is the corner solution (i.e.,  $t_{NN}^* \geq t_{SN}$ ), on the other hand, either  $W_{NN}(t_{SN})$  or  $W_{SN}(t_{SN})$  is the global maximum.*

Therefore, we obtain the following proposition.

**Proposition 3** *The South can attain the highest welfare by lowering the tariff. Under the optimal tariff, either the  $NN$  duopoly or the  $SN$  duopoly arises.*

Figures 2 - 4 show three possible cases. The horizontal axis measures tariff rate. The vertical axis measures South welfare, profits of firm  $N_1$ , profits of firm  $S$ , price of the final good, and tariff revenue,  $TR$ . In Figures 2 and 3, South welfare is maximized under the  $SN$  duopoly. Whereas  $b + 2c^N - 3c^S \leq 0$  holds in Figure 2, and  $b + 2c^N - 3c^S > 0$  in Figures 3. In Figure 4, South welfare is maximized under the  $NN$  duopoly.

**Figures 2 - 4 around here**

## 6 The Effects of Subsidies

In this section, we investigate the effects of subsidies on technology transfer. We first show that a production subsidy to firm  $S$  may also induce technology transfer. To compare subsidies with tariffs, we keep the  $N$  monopoly as our benchmark equilibrium. That is,  $0 \leq t_0 \leq c^S - c^N$  (where the tariff rate  $t_0$  is constant in this section) holds.

By providing a specific production subsidy,  $s$ , to firm  $S$ , its effective MC becomes  $c^e \equiv c^S - s$ . Simply replacing  $c^S$  in the previous analyses with  $c^e$ , we can verify that the  $NS$  duopoly arises if

$$s > s_{NS} \equiv c^S - c^N - t_0$$

and the  $S$  monopoly arises if

$$s > s_S \equiv \frac{18(c^S - c^N - t_0) + (b - c^S)(10 - \sqrt{10})}{8 + \sqrt{10}}.$$

Intuitively, the subsidy allows firm  $N_1$  to charge the higher price for the intermediate good

$$r_{NS} = \frac{5b - [c^N + t + 4(c^S - s)]}{10}, r_S = \frac{b - (c^S - s)}{2}$$

and hence firm  $N_1$  has more incentive to sell the intermediate good. Through the price hike, a part of the subsidy shifts from firm  $S$  to firm  $N_1$ .<sup>21</sup>

We next consider an import subsidy to the intermediate good. In the case of the import subsidy, the price of the intermediate good becomes lower by  $s$  relative to the case of the production subsidy. A part of the import subsidy shifts from firm  $N_1$  to firm  $S$  due to the lower import price. In fact, we can easily confirm that the other equilibrium values are identical between the two subsidies. This is because the South does not produce the intermediate good.

In our model, therefore, we obtain

**Proposition 4** *A specific production subsidy to the final good and a specific import subsidy to the intermediate good set at the same levels are equivalent. A subsidy may induce technology transfer from firm  $N_1$  to firm  $S$ .*

Next we explore the welfare effect. Obviously, a subsidy has no effect on the economy under the  $N$  monopoly. Under the  $NS$  duopoly, welfare is given by

$$\begin{aligned} W_{NS}(s) = & -\frac{1}{200a} [44s^2 + (68t_0 - 20b + 28c^N - 8c^S) s + c^N (58t + 52c^S) \\ & + 99t_0^2 - 41(c^N)^2 - 36(c^S)^2 + 12c^S t_0 + 10b (3c^N - 7t_0 + 2c^S) - 25b^2]. \end{aligned}$$

The subsidy rate that maximizes  $W_{NS}(s)$  without any constraint is given by

$$s_{NS}^* \equiv \frac{5b - 7c^N + 2c^S - 17t_0}{22}.$$

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<sup>21</sup>See Ishikawa and Spencer (1999) for the rent-shifting in vertically related markets.

Noting  $t_0 \leq c^S - c^N$ , we can show

$$s_S - s_{NS}^* = \frac{(95 - 22\sqrt{10})(b - c^N) + 60(c^S - c^N - t_0) + (22\sqrt{10} - 65)t_0}{66} > 0.$$

Since  $W_N(0) = W_N(s_{NS}) = W_{NS}(s_{NS})$  holds, an increase in  $s$  improves welfare under the  $NS$  duopoly only if  $s_{NS} < s_{NS}^*$ .

Under the  $S$  monopoly, we obtain

$$W_S(s) = \frac{(3b - 3c^S - 5s)(b - c^S + s)}{32a}.$$

Thus, as  $s$  rises, welfare deteriorates under the  $S$  monopoly. Moreover,  $W_{NS}(s_S) > W_S(s_S)$  holds.

Thus, the globally optimal subsidy is 0 if  $s_{NS} \geq s_{NS}^*$  and  $s_{NS}^*$  otherwise. We have

$$s_{NS} - s_{NS}^* = -\frac{5[(b + 2c^N - 3c^S) + (t_0 - c^S + c^N)]}{22}. \quad (48)$$

If  $b + 2c^N - 3c^S \leq 0$ , (48) has the non-negative sign because  $t_0 \leq c^S - c^N$ . Therefore, welfare is maximized under the  $N$  monopoly (i.e.,  $s = 0$ ). If  $b + 2c^N - 3c^S > 0$ , on the other hand,  $s_{NS} < s_{NS}^*$  may hold. In this case, the maximum welfare is obtained under the  $NS$  duopoly at  $s_{NS}^*$ .

Thus, the following proposition is established.

**Proposition 5** *The optimal production or import subsidy is zero if  $b + 2c^N - 3c^S \leq 0$  and either zero or  $s_{NS}^*$  if  $b + 2c^N - 3c^S > 0$ . The optimal subsidy results in technology transfer when it is  $s_{NS}^*$ .*

We now compare the maximum welfare under the subsidy with that under the tariff on the final good. When  $b + 2c^N - 3c^S \leq 0$ , it is obvious that the maximum welfare is higher under the tariff than under the subsidy. Thus, we examine the case with  $b + 2c^N - 3c^S > 0$ . We have

$$\begin{aligned} W_{NS}(t_{NS}^*) - W_{NS}(s_{NS}^*) &= \frac{1}{99a} (b - c^N - 3t_0) (5b - 2c^N - 3c^S - 12t_0) \\ &> \frac{1}{99a} (b + 2c^N - 3c^S) [5(b + 2c^N - 3c^S)] > 0, \end{aligned}$$

where the inequality comes from  $t_0 \leq c^S - c^N$ .

Therefore, we obtain

**Proposition 6** *The maximum welfare obtained under the production or import subsidy is less than that under the tariff on the final good.*

## 7 Discussion

To make our point as clearly as possible, we have considered a highly stylized model. Thus, one may wonder to what extent our results are robust. In this section, we discuss some alternative assumptions to gain some more insight.

We first consider the assumption about the price-setting of the intermediate good. We have assumed that firm  $N_1$  sets the price of the intermediate good regardless of a single buyer, i.e., firm  $S$ . This is basically because firm  $S$  has to purchase the intermediate good to start production, but this assumption is not essential to the basic insight of our analysis. An alternative assumption could be bargaining between firms  $N_1$  and  $S$ . When firm  $S$  has some bargaining power, the equilibrium price of the intermediate good becomes lower. However, the two motives for technology transfer would not disappear. In fact, Lemma 2 suggests that in the case of “entry-detering” technology transfer, firm  $N_1$  has incentive to provide firm  $S$  with the intermediate good even without any charge. On the other hand, firm  $N_1$  may have complete bargaining power so that it decides both price and supply of the intermediate good. In this case, firm  $N_1$  can extract all surplus and hence both motives are reinforced.

For simplicity, we have assumed that only firm  $N_1$  can transfer technology to firm  $S$ . It is worthwhile modeling a stage that determines which North firm transfers the technology. In the following situation, however, our model and results do not require any major changes. Two North firms, firms  $N_1$  and  $N_2$  have two different technologies and compete in technology transfer to firm  $S$ . Each technology requires a specific intermediate good. That is, the intermediate goods produced by firms  $N_1$  and  $N_2$  are differentiated. Firm  $S$  adopts either of the two technologies. Once one technology is adopted, the other is idle. Moreover, consumers regard the final good produced by firms  $N_1$  and  $N_2$  as homogeneous.<sup>22</sup> For example, typical eco-friendly cars are currently hybrid vehicles and diesel vehicles. Their engines are completely different. Once a firm decides to manufacture hybrid cars, for instance, diesel engines are useless.<sup>23</sup> If firm  $N_1$  can produce its intermediate good more cheaply than firm  $N_2$ , then it can let firm  $S$  adopt its technology and become the sole supplier of the intermediate good.

We have also assumed a single potential entrant in the South. If there are multiple potential entrants in the South, an oligopoly among the incumbent firm and multiple South firms could arise instead of the  $NN$  duopoly. If this is the case, the possibility of technology transfer expands. It is of interest to examine the technology transfer with general number of the firms. However, it is likely that entry-detering technology transfer as well as tariff-jumping technology transfer still arise even in more general settings.

## 8 Concluding Remarks

We have examined the relationship between tariffs on a final good and technology transfer in vertically related markets. Specifically, technology is embodied in a key component which only the North firm can produce. Interestingly, not only tariff-hikes but also tariff-reductions may lead to technology transfer. “Tariff-jumping” technology transfer may occur in the case of tariff-hikes,

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<sup>22</sup> Even if the final goods are also differentiated, our results are still valid as long as they are close substitutes.

<sup>23</sup> Similar examples include plasma display panel vs. liquid crystal display panel in TV production and Blu-ray Disc vs. High-Definition Digital Versatile Disc (HD DVD) in DVD-player production.



while “entry-detering” technology transfer may occur in the case of tariff-reductions. Although tariff-jumping technology transfer is somewhat similar to tariff-jumping FDI, entry-detering technology transfer is specific to technology transfer. In particular, our policy implication that the South should take pro-competitive policies to facilitate technology transfer seems to be novel. Besides tariff-reductions, pro-competitive policies include any measures to decrease the setup cost to start exports, for example.

We have also shown that a production subsidy to the final good or an import subsidy to the intermediate good may lead to technology transfer. This is because the North firm can earn more profit by selling the intermediate good to the South firm. However, a decrease in the tariff on the final good generates higher welfare than the subsidies.

We can easily incorporate licensing into our analysis. In particular, we can simply reinterpret the price of the intermediate good as the sum of the price of the intermediate good and the per-unit royalty.<sup>24</sup> Thus, the analysis on tariffs on the final good needs no modification even if the intermediate good is replaced by technology licensing. There are several reasons why we have specifically considered technology transfer through trade in a key component. First, the North firm can easily stop transferring technology by foreclosure. In the case of licensing, on the other hand, it may be difficult for the licensor to completely stop technology transfer after the licensee has learned the know-how. Second, we can get rid of arguments over the optimal licensing contracts. There are a number of variations in licensing contracts. In particular, the licensing literature has extensively compared between per-unit royalty and fixed fee. Third, we can examine the relationship between technology transfer and policies related to the intermediate good. Last and more importantly, considering the intermediate-product market rather than the licensing market, we can particularly argue that North firms may have incentive to transfer their technologies to South firms even if the licensing market does not exist or is restricted, which has been observed in many developing countries.

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<sup>24</sup>We analyze this aspect in detail elsewhere (Horiuchi and Ishikawa, 2007).

## Appendix

### The general form of the equilibrium in the last stage

$$x^{N_i} = \begin{cases} \frac{(b-c^N-t)+n^S(r+c^S-c^N-t)}{a(n^N+n^S+1)} & \text{if } n^N \neq 0 \\ 0 & \text{if } n^N = 0 \end{cases}, \quad (\text{A1})$$

$$x^S = \begin{cases} \frac{(b-r-c^S)+n^N(c^N+t-r-c^S)}{a(n^N+n^S+1)} & \text{if } n^S \neq 0 \\ 0 & \text{if } n^S = 0 \end{cases}, \quad (\text{A2})$$

$$p = \frac{b + n^S(r + c^S) + n^N(c^N + t)}{n^N + n^S + 1}, \quad (\text{A3})$$

$$X = \frac{(n^N + n^S)b - n^S(r + c^S) - n^N(c^N + t)}{a(n^N + n^S + 1)}, \quad (\text{A4})$$

$$\pi^{N_i f} = \begin{cases} \frac{1}{a} \left[ \frac{(b-c^N-t)+n^S(r+c^S-c^N-t)}{n^N+n^S+1} \right]^2 - f_i & \text{if } n^N \neq 0 \\ 0 & \text{if } n^N = 0 \end{cases}, \quad (\text{A5})$$

$$\pi^{N_1 m} = \begin{cases} r \frac{(b-r-c^S)+n^N(c^N+t-r-c^S)}{a(n^N+n^S+1)} & \\ 0 & \text{if } n^S = 0 \end{cases}, \quad (\text{A6})$$

$$\pi^S = \begin{cases} \frac{1}{a} \left[ \frac{(b-r-c^S)+n^N(c^N+t-r-c^S)}{n^N+n^S+1} \right]^2 & \text{if } n^S \neq 0 \\ 0 & \text{if } n^S = 0 \end{cases}, \quad (\text{A7})$$

where  $n^N$  and  $n^S$  are, respectively, the number of the North and the South firms in the final-good market and  $f_1 = 0$ .

### Proof of Lemma 1

Under the oligopoly among three firms, firm  $N_1$  offers firm  $S$  the intermediate-good price that maximizes  $\pi_{NSN}^{N_1}$ , subject to  $\pi_{NSN}^S \geq 0$ . The constraint can be rewritten as  $x_{NSN}^S \geq 0$  and hence

$$r \leq \bar{r}_{NSN} \equiv \frac{b - 3c^S + 2(c^N + t)}{3}.$$

On the other hand,  $r$  that maximizes  $\pi_{NSN}^{N_1}$  without any constraint is given by

$$r_{NSN} = \frac{3b - 5c^S + 2c^N + 2t}{11}.$$

Thus,  $r_{NSN} \leq \bar{r}_{NSN}$  holds if and only if  $t > t_{NSN} \equiv (-b + 9c^S - 8c^N)/8$ . This implies that the oligopoly among three firms prevails only if  $t > t_{NSN}$ .

By noting

$$\bar{t} - t_{NSN} = \frac{5b - 5c^S - 16\sqrt{af_2}}{8} < 0$$

under (23), the oligopoly equilibrium does not arise if  $t_{SN} < \bar{t}$  holds (where  $\bar{t}$  is defined by (36)). In the following, therefore, we show  $t_{SN} < \bar{t}$ .

$$\begin{aligned}
\bar{t} - t_{SN} &= \frac{1}{38} \left( -10b + 10c^S + 8\sqrt{af_2} + \sqrt{\left[9 \left( b - c^S - \frac{52}{27}\sqrt{af_2} \right)\right]^2 + \frac{6080}{9}af_2} \right) \\
&= \frac{1}{38} \left( -10[(b - c^N - (4/5)\sqrt{af_2}) - (c^S - c^N)] + \sqrt{\left[9 \left( b - c^S - \frac{52}{27}\sqrt{af_2} \right)\right]^2 + \frac{6080}{9}af_2} \right)
\end{aligned}$$

With (23),  $b - c^N - (4/5)\sqrt{af_2} > 0$  holds. Thus, we obtain

$$\begin{cases} -10b + 10c^S + 8\sqrt{af_2} > 0 & \text{if } c^N + (b - c^N - (4/5)\sqrt{af_2}) < c^S \\ -10b + 10c^S + 8\sqrt{af_2} \leq 0 & \text{if } c^S \leq c^N + (b - c^N - (4/5)\sqrt{af_2}) \end{cases}$$

Then,  $t_{SN} < \bar{t}$  holds when  $c^N + (b - c^N - (4/5)\sqrt{af_2}) < c^S$ . We now prove  $t_{SN} < \bar{t}$  also holds when  $c^S \leq c^N + (b - c^N - (4/5)\sqrt{af_2})$ . For this, we show

$$\begin{aligned}
&\sqrt{\left[9 \left( b - c^S - \frac{52}{27}\sqrt{af_2} \right)\right]^2 + \frac{6080}{9}af_2} > 10b - 10c^S - 8\sqrt{af_2} \Leftrightarrow \\
&\left[9 \left( b - c^S - \frac{52}{27}\sqrt{af_2} \right)\right]^2 + \frac{6080}{9}af_2 > (10b - 10c^S - 8\sqrt{af_2})^2 \Leftrightarrow \\
&-19(b - c^S - 4\sqrt{af_2})(b - c^S + 12\sqrt{af_2}) > 0
\end{aligned}$$

In view of (23),  $b - c^S - 4\sqrt{af_2} < 0$ . Also noting  $c^S - c^N \leq b - c^N - (4/5)\sqrt{af_2}$ , we have

$$\begin{aligned}
b - c^S + 12\sqrt{af_2} &= (b - c^N - 3\sqrt{af_2}) + 15\sqrt{af_2} - (c^S - c^N) \\
&> (b - c^N - 3\sqrt{af_2}) + 15\sqrt{af_2} - (b - c^N - \frac{4}{5}\sqrt{af_2}) \\
&= \frac{64}{5}\sqrt{af_2} > 0
\end{aligned}$$

Thus,  $t_{SN} < \bar{t}$  also holds when  $c^S \leq c^N + (b - c^N - (4/5)\sqrt{af_2})$ .

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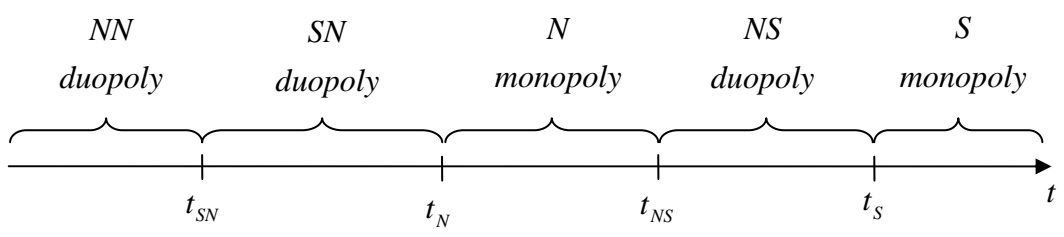
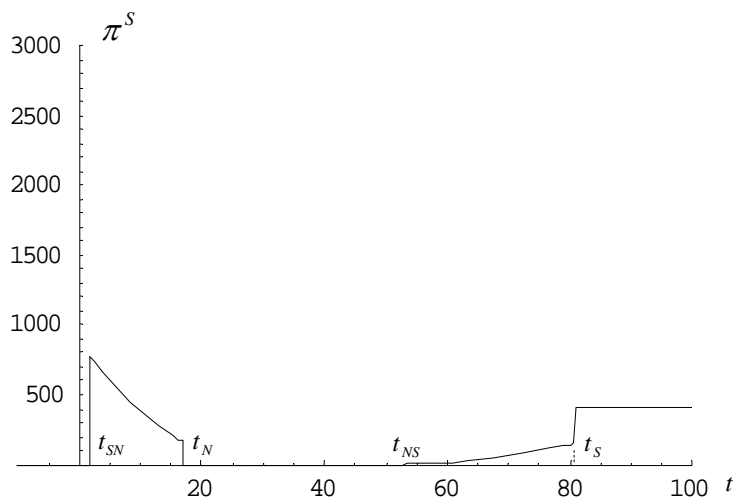
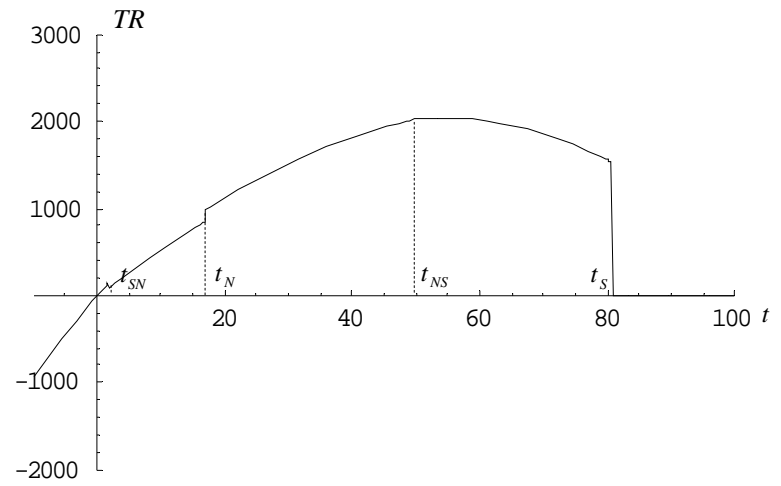
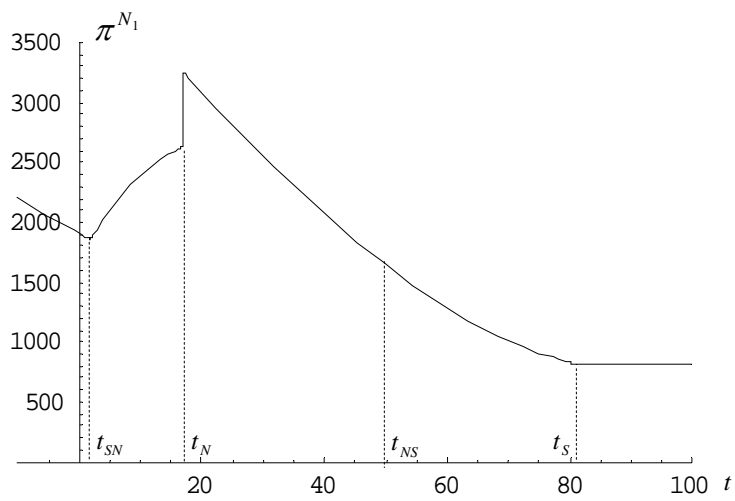
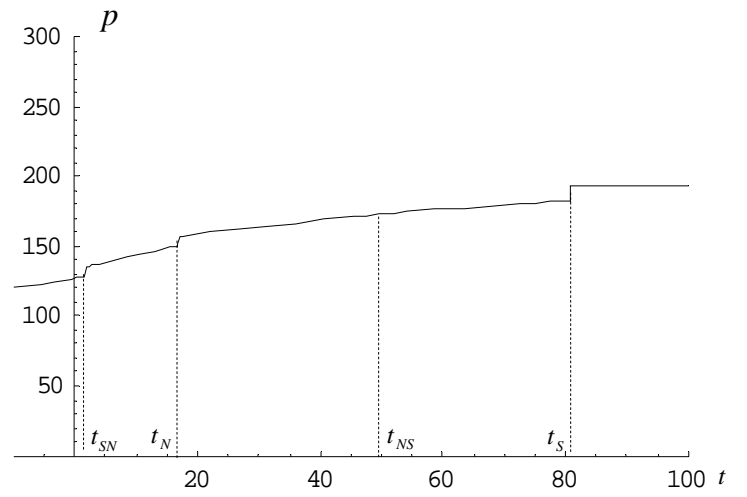
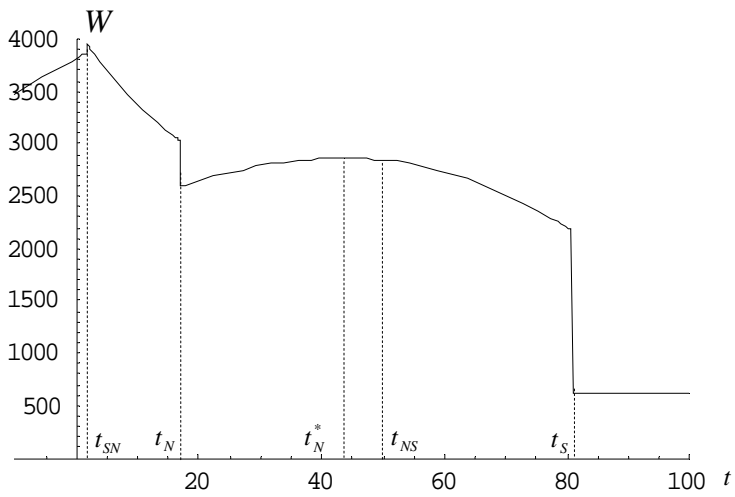


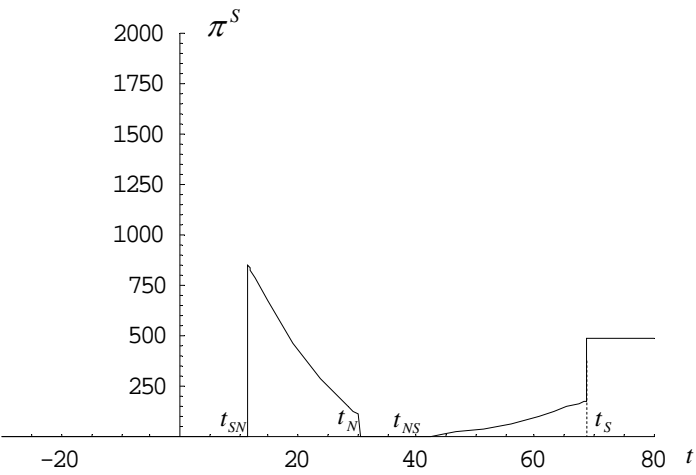
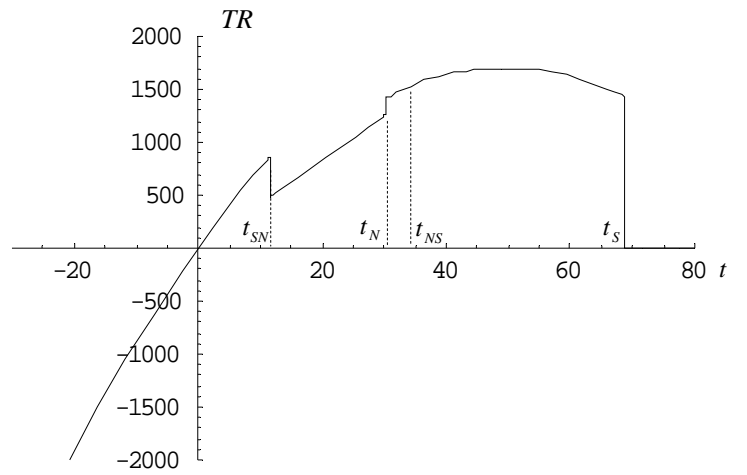
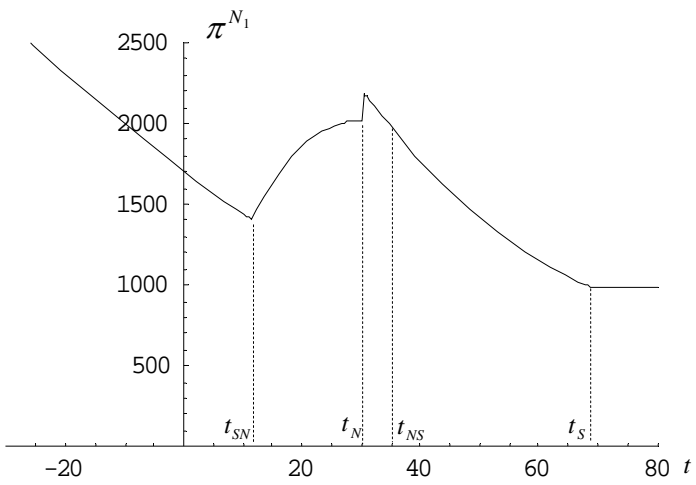
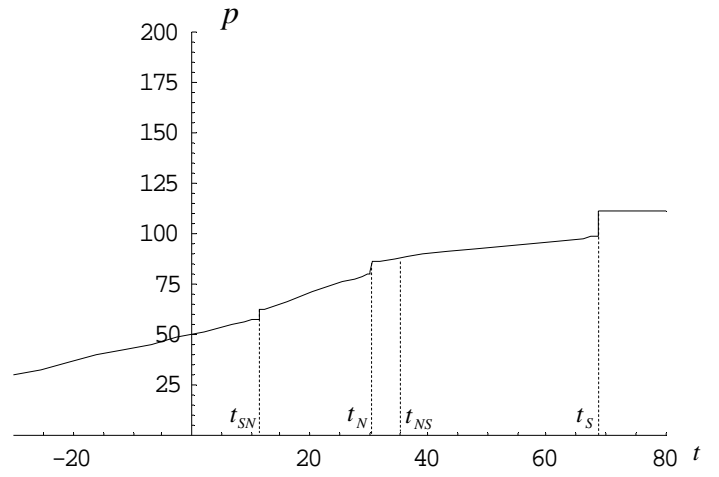
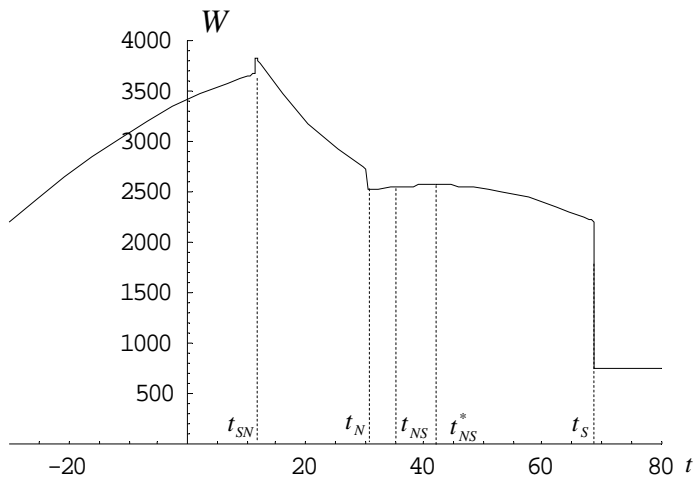
Figure 1: Tariffs and market structures



$t_{SN}$	$t_N$	$t_{NS}$	$t_S$
1.8	17.0	50.0	80.8

$a$	$b$	$c^S$	$c^N$	$f_2$
1.0	214.0	133.0	83.0	1444.0

Figure 2: Welfare-maximizing market structure: the SN duopoly ( $b + 2c^N - 3c^S \leq 0$ )



$t_{SN}$	$t_N$	$t_{NS}$	$t_S$
11.5	30.3	35.0	68.8

$a$	$b$	$c^S$	$c^N$	$f_2$
1.0	133.0	44.0	9.0	975.0

Figure 3: Welfare-maximizing market structure: the SN duopoly ( $b + 2c^N - 3c^S > 0$ )

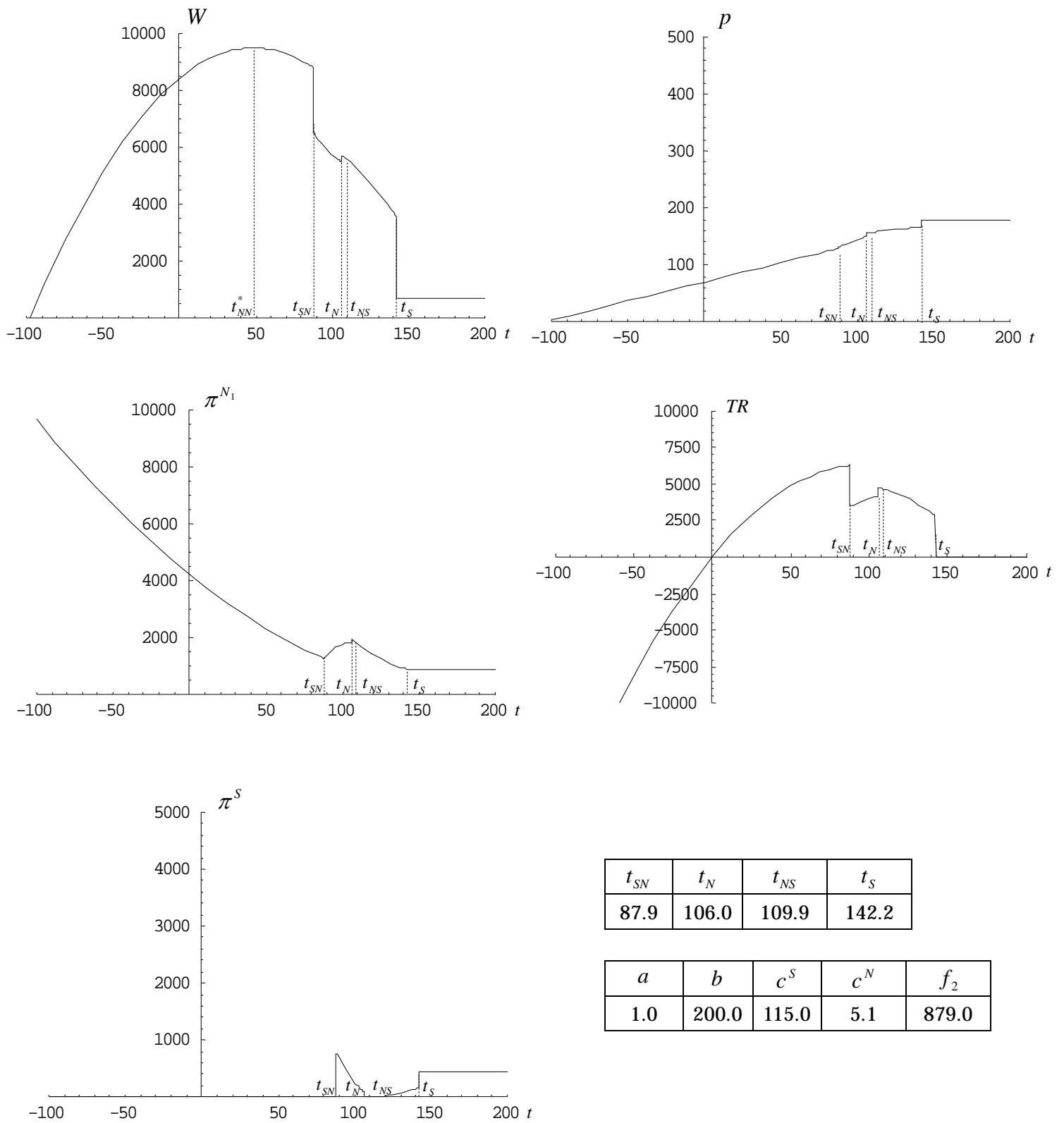


Figure 4: Welfare-maximizing market structure: the NN duopoly