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

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Abstract

We examine the relationship between tariffs and North–South technology transfer in an oligopoly model when technology is embodied in a key component that only North firms can produce. They may have an incentive to transfer their technologies to South firms even if the South's licensing market is restricted or if intellectual property right protection is imperfect in the South. Interestingly, a decrease in the tariff on the final good as well as an increase may induce technology transfer. Our analysis suggests that the South should implement pro–competitive policies to induce technology transfer and enhance welfare.

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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 that the South is unable to produce.[1] In this case, even if the South has the know–how required to produce final products, the South cannot produce those final products by itself. To produce final products, the South must import key inputs from the North. For example, when Hyundai Motor Co. (a Korean car producer) manufactured the first Korean car in 1975, the engine was provided by Mitsubishi Motors Co. (a Japanese car producer), which transferred its technology to Hyundai.[2]

North–South technology transfer through trade in intermediate products differs from licensing, which is a typical channel for technology transfer, in an important way. Governments of the South often demand technology transfer without offering payments for licensing. Even if there are licensing opportunities, governments of the South sometimes impose regulations such as caps on royalty rates.[3] Moreover, intellectual property rights are often not well enforced in the South. Under such circumstances, licensing is likely to be discouraged. However, this is not necessarily the case for technology transfer embodied in intermediate products, because the North benefits from selling intermediate products that the South cannot produce.

We consider North–South technology transfer through trade in intermediate products. Developing a simple oligopoly 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.[4] A well–known relationship is tariff–jumping FDI, under which higher tariffs induce exporting firms to undertake FDI. However, there are few theoretical studies (referred to below) of the relationship between tariffs and technology transfer.

As does FDI, in our model, an increase in the tariff on a final good leads to "tariff–jumping" technology transfer. A North firm, which exports a final good to the South, loses out if the South raises its tariff. To offset this loss, the North firm may have an incentive to provide its technology to a potential local entrant (that is, a South firm) 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 detrimental 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 to compete with the incumbent North firm, the North firm's loss is smaller because it benefits from selling the intermediate product to the South firm. That is, the incumbent North firm may strategically engage in "entry–deterring" technology transfer. Thus, a tariff reduction as well as a tariff increase may induce technology transfer.

Tariffs are not necessary for the entry–deterring technology transfer. Any policy that encourages entry could result in technology transfer. This contrasts with the conventional policy of inducing technology transfer through FDI. It has been observed that governments from the South have guaranteed firms from the North market power in return for technology transfer under obligation to form joint ventures (JVs) with South firms.[5] Our analysis suggests that pro–competitive policies that raise entry should be effective without forcing North firms to transfer technology. Moreover, according to our analysis, FDI is not necessary for technology transfer.

Lin and Saggi (1999), Pack and Saggi (2001) and Ishikawa and Horiuchi (2008) also consider strategic uses of the North–South technology transfer.[6] In particular, Lin and Saggi (1999), in a dynamic North–South model, show that FDI facilitates the imitation of advanced technology by South firms and intensifies competition in the South market. Hence, FDI by a North firm may cause other North firms to delay switching from exports to FDI. However, their primary purpose is to show a paradoxical result that technology spillovers to local firms through FDI may facilitate, rather than discourage, FDI.

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 an 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 the licensing to potential entrants by a foreign monopolist and the timing of the imposition of the (optimal) tariff. Although our analysis is related to theirs, our focus is quite different. We consider both tariff reductions and increases. In particular, we show that technology transfer induced by tariff reductions raises welfare by more than does technology transfer induced by tariff increases.

In our model, selling an intermediate product can be interpreted as licensing based on per–unit royalty without affecting 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. In particular, she points out that a patentee–monopolist may have an incentive to license its technology to a weak entrant to deter a strong entrant from entering the market. Eswaran (1994) generalizes Rockett's (1990) analysis.[7] However, both of these studies assume licensing with two–part tariffs (that is, a fixed fee plus a per unit royalty).[8] Moreover, they do not consider welfare implications. More importantly, their main concerns are the industrial and market structures under licensing, whereas we focus on North–South technology transfer through trade in an intermediate good and the associated policy implications.

The rest of the paper is organized as follows. In Section 2, we develop the basic model. In Section 3, we investigate the effects on technology transfer of an increase in the tariff on a final good. In Section 4, we examine the corresponding effects of a tariff reduction. In Section 5, we analyze economic welfare. In Section 6, we discuss some alternative assumptions. Section 7 concludes the paper.

## 2 The Basic Model

There are two countries, North and South. We consider interactions among an incumbent, a North firm (firm $N_1$), and two potential entrants, another 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.[9] Firm $N_2$ incurs fixed costs (FCs), $f_2$, in serving the South market.[10] To start production, firm $S$ requires technology to be transferred by firm $N_1$, that is, firm $S$ must purchase a key intermediate good from firm $N_1$. Firm $N_2$ does not supply its intermediate good to firm $S$.[11] The South government imposes a specific tariff, $t$, on the final good. To focus on the relationship between technology transfer and the tariff on the final good, we assume that there is no tariff on the intermediate good. If more than one firm serve the South market, these firms engage in Cournot competition. The inverse demand is given by the following linear function:[12]

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

where $p$ and $X$ are, respectively, the price of, and the demand for, the final good, and $a$ 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) of producing the intermediate product is normalized to zero. Firm $N_1$ charges firm $S$ a price of $r$ for its intermediate good. The MC of producing the final product from the intermediate good is $c^N$ in the North and $c^S$ in the South. Even if technology is transferred, firm $N_1$ produces the final good more efficiently than does firm $S$. Specifically, $c^N < c^S$ and $b > c^N + t$ which are assumptions needed to establish our benchmark case (in which firm $N_1$ is a monopolist). For example, $c^N < c^S$ reflects the managerial inefficiency of firm $S$. The profits of firms $N_1$, $N_2$, and $S$ are, respectively, given by

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

where $x^i$ $(i = N_1, N_1, S)$ is the output of firm $i$; and $\pi^{N_i f}$ and $\pi^{N_1 m}$ are, respectively, the profits from the final–good market and the intermediate–good market.

The model involves four stages of decision making. 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 this offer. 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 served by either firm $N_1$, firm $S$, or firm $N_2$; there is a duopoly between either firms $N_1$ and $S$, firms $N_1$ and $N_2$, or firms $S$ and $N_2$;

there is an oligopoly of the three firms, $N_1$, $N_2$ and $S$. However, firm $N_2$ cannot be a monopolist in equilibrium. Moreover, a duopoly between firms $S$ and $N_2$ does not constitute an equilibrium. This is because firm $N_1$ has no incentive to abandon its duopoly with firm $S$ and allow it to be replaced by one between firms $S$ and $N_2$.

# 3 The Effects of a Tariff Increase

In this section, we analyze the effects of tariff increases on technology transfer. In our analysis, the benchmark case is represented by a monopoly for firm $N_1$ (henceforth the $N$ monopoly) under a non–negative tariff.[13] That is, firm $N_1$ initially monopolizes the market. Then the equilibrium is given by the following equation:[14]

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

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

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

An increase in $t$ lowers the potential profits of firm $N_2$ and thus does not induce firm $N_2$'s entry. Hence, the possible equilibria are the $N$ monopoly, the duopoly between firms $N_1$ and $S$ (henceforth the $NS$ duopoly), and a monopoly for firm $S$ (henceforth the $S$ monopoly).

In the last stage, the $NS$ duopoly equilibrium is as follows:[15]

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

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

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

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

The $S$ monopoly equilibrium is

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

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

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

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

In stage 1, given $t$, firm $N_1$ chooses its preferred market structure through technology transfer. Clearly, technology is not transferred under the $N$ monopoly. Under the $NS$ duopoly, firm $N_1$ determines $r$ to maximize profits $\pi_{NS}^{N_1}$ subject to $\pi_{NS}^{S} > 0$ and $\pi_{NS}^{N_1 f} > 0$ (that is, $x_{NS}^{S} > 0$ and

$x^{N_1}_{NS} > 0$). We determine under what condition $x^{S}_{NS} > 0$ and $x^{N_1}_{NS} > 0$. Given (4), the constraints are equivalent to the following:[16]

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

The $r$ that maximizes the unconstrained $\pi^{N_1}_{NS}$ is

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

It is easy to verify that $\widetilde{r}_{NS} < r_{NS} < \overline{r}_{NS}$ holds if and only if

$$c^S - c^N \equiv t_{NS} < t < \widetilde{t} \equiv \frac{5b + 2c^S - 7c^N}{7}. \tag{13}$$

When $\widetilde{r}_{NS} < r_{NS} < \overline{r}_{NS}$, we obtain the duopoly equilibrium by substituting $r_{NS}$ into (4) to (7):

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

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

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

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

When $t$ is sufficiently high, firm $N_1$ exits the final–good market and exports only the intermediate good, the price of which is determined to maximize $\pi^{N_1}_{S}$. Such an $r$ is given by

$$r_S = \frac{b - c^S}{2}. \tag{18}$$

Hence, the equilibrium is given by

$$x^S_S = \frac{b - c^S}{4a}, \tag{19}$$

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

$$\pi^{N_1}_S = \frac{(b - c^S)^2}{8a}, \tag{21}$$

$$\pi^S_S = \frac{(b - c^S)^2}{16a}. \tag{22}$$

We can now determine the market structures. First, it is easy to verify that $\pi^{N_1}_N = \pi^{N_1}_{NS}$ at $t_{NS}$. Thus, when $t$ reaches $t_{NS}$, firm $N_1$ starts exporting the intermediate good. We next derive the tariff rate, $t_S$, under which firm $N_1$ stops serving the final–good market. From $\pi^{N_1}_{NS} = \pi^{N_1}_S$, 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 $\widetilde{t}$ and hence $x^{N_1}_{NS} > 0$ at $t_S$. Even if $x^{N_1}_{NS} > 0$, 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 $N$ monopoly to the $S$ monopoly.

The above analysis is used to establish the following proposition.

**Proposition 1** *Suppose that 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 behind technology transfer is straightforward. As the tariff increases, the profits of firm $N_1$ decrease. To offset the loss, the firm 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 tariff–jumping technology transfer.

# 4 The Effects of a Tariff Reduction

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

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

As we show below, under this assumption, the monopoly market structure is abandoned following a fall in $t$.[17] In what follows, we investigate how the market structure changes.

In the absence of firm $N_2$, a decrease in $t$ does not generate technology transfer. However, when $t$ becomes low enough for firm $N_2$ to cover its FCs, 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). This is 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 firm $N_1$ sets the price of the intermediate good below the monopoly price to induce 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:

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

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.,

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

Given (23), $t_N \geq 0$. Because 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, given (23), $t_N < t_{NS} (\equiv c^S - c^N)$ holds.

When $t$ falls to $t_N$, 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 below. When the three firms compete in the market, the profits of firm $N_2$ are given by

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

Firm $N_1$ sets $r$ so that firm $S$ enters the market and $\pi^{N_2}_{NSN} = 0$.[18] That is,

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

Substituting $r_{SN}$ into (4)-(7) yields the duopoly equilibrium

$$x^{N_1}_{SN}(t) = \frac{4\sqrt{f_2}}{3\sqrt{a}}, x^S_{SN}(t) = \frac{3b - 3(c^N + t) - 8\sqrt{af_2}}{3a}, \tag{27}$$

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

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

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

As $t$ falls, firm $N_1$ must decrease $r_{SN}$ to deter firm $N_2$'s entry. When $r$ has fallen sufficiently, firm $N_1$ may lose its incentive to deter entry. In this case, firm $N_1$ has two options. One is to let firm $N_2$ simply enter the market, and the other is to let firm $N_2$ enter the market but force firm $S$ to exit the market. Firm $N_1$ compares the profits generated by the three–firm oligopoly (henceforth the $NSN$ oligopoly) with those from the $NN$ duopoly. If the duopoly profits exceed the oligopoly profits, firm $N_1$ ceases to provide the intermediate good to firm $S$ and firm $S$ is forced to exit the market; that is, foreclosure occurs. However, if the oligopoly profits exceed the duopoly profits, the $NSN$ oligopoly prevails.

Equilibrium under the $NN$ duopoly is given by

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

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

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

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

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

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

The following lemma (shown in the appendix) indicates that only the $NN$ duopoly arises when $t < t_{SN}$.

**Lemma 1** *An $NSN$ oligopoly equilibrium arises only if $t > t_{NSN} \equiv (-b + 9c^S - 8c^N)/8$. However, given (23), $t_{NSN} > t_{SN}$. Thus, no $NSN$ oligopoly equilibrium can arise.*

Intuitively, although firm $N_1$ can earn profits by selling the intermediate good to firm $S$ under the $NSN$ oligopoly, it does so at the expense of making lower profits in the final–good market. Since the latter negative effect dominates the former positive effect, firm $N_1$ vertically forecloses.

We note the following points. First, $r_{SN} = 0$ may hold with $t > t_{SN}$. We let $\bar{t}$ denote the tariff rate that results in $r_{SN} = 0$:

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

As shown in the proof of Lemma 1, $\bar{t} > t_{SN}$ holds. Thus, we obtain the following lemma:[19]

**Lemma 2** *Firm $N_1$ is prepared to sell its intermediate good to firm $S$ at a price below MC in order to deter firm $N_2$ from entering the market.*

Second, noting that $t_N \geq 0$, it is easy to verify that $t_{SN} < t_N$. Therefore, when $t$ falls, the market structure does not directly change from the $N$ monopoly to the $NN$ duopoly. Firm $N_1$ benefits from deterring 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 monopolizes the South's final–good market. Firms $N_1$ and $S$ serve the South's 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, a sufficiently large decrease eliminates technology transfer.*

Figure 1 summarizes the relationship between tariff rates and market structure implied by Propositions 1 and 2.

**<Figure 1 around here>**

# 5 Welfare Analysis

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

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

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

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

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

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

The function is convex. With no constraint on $t$, $W_{NS}$ takes its maximum value, given by

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

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

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

Thus, $W_{NS}^* > W_{NS}(t_S) > W_S$. Hence, we can state the following lemma.

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

We next compare welfare under the $NS$ duopoly with that 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

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

which is quadratic and convex. With no constraint on $t$, $W_N$ takes its maximum value, given by

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

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

Straightforward but tedious calculations reveal that (i) $W_N(t_{NS}) = W_{NS}(t_{NS})$; (ii) $t_{NS} < t_{NS}^*$ if and only if $b + 2c^N - 3c^S > 0$; and (iii) $t_{NS} < t_N^*$ if and only if $b + 2c^N - 3c^S > 0$. Therefore, we can state the following lemma.

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

The intuition behind 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 left–hand side is related to market size, while the right–hand side is related to the difference in efficiency. This condition is likely to hold when the market is relatively large and/or when firm $S$ is not very inefficient relative to firm $N_1$. Consumer surplus is smaller under the $NS$ duopoly than under the $N$ monopoly.[20] However, when the market is relatively large and/or when firm $S$ is not very inefficient relative to firm $N_1$, firm $S$'s profits are relatively large and an increase in the tariff is likely to raise tariff revenue under the $NS$ duopoly. Thus, the lemma holds.

Welfare under the $SN$ duopoly is

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

This function is quadratic and concave. With no 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 $t = t_{SN}$, which is given by

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

Welfare under the $NN$ duopoly is

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

This is quadratic and convex. With no constraint on $t$, $W_{NN}$ takes its maximum value, which is given by

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

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

Tedious calculations yield the following lemmas.

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

**Lemma 6** *Suppose that $b+2c^N-3c^S \leq 0$. Then $W_{NN}(t_{SN})$ is greater than the maximum welfare level 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 global maximum. However, if the optimal tariff under the $NN$ duopoly is the corner solution (i.e., $t_{NN}^* \geq t_{SN}$), then $W_{NN}(t_{SN})$ is the global maximum with $t_N^* < t_N$ but either $W_{NN}(t_{SN})$ or $W_{SN}(t_{SN})$ is the global maximum with $t_N^* \geq t_N$.*

Therefore, we can state the following proposition.

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

Figures 2 to 4 illustrate three possible cases. The horizontal axis measures the tariff rate. The vertical axis measures welfare in the South. In Figures 2 and 3, the South's welfare is maximized under the $SN$ duopoly. Whereas $b + 2c^N - 3c^S \leq 0$ holds in Figure 2, $b + 2c^N - 3c^S > 0$ in Figures 3. In Figure 4, the South's welfare is maximized under the $NN$ duopoly. Our analysis suggests that the South should adopt pro–competitive policies to induce technology transfer and thereby enhance welfare.

**<Figures 2–4 around here>**

# 6 Discussion

For clarity, 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 more insights.

We first consider the assumption about the setting of intermediate–good prices. We have assumed that firm $N_1$ sets the price of the intermediate good without considering the effect of the single buyer, firm $S$. This is because firm $S$ must purchase the intermediate good to begin production. However, this assumption is not essential to our analysis. An alternative assumption could be that there is bargaining between firms $N_1$ and $S$. When firm $S$ has some bargaining power, the equilibrium price of the intermediate good falls. However, the two motives for technology transfer (that is, tariff–jumping and entry–deterrence) would remain. In fact, Lemma 2 suggests that in the case of "entry–deterring" technology transfer, firm $N_1$ may have an incentive to provide the intermediate good to firm $S$ for free. On the other hand, firm $N_1$ may have complete bargaining power so that it determines both the price and supply of the intermediate good. In this case, firm $N_1$ can extract all the 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 worth modeling a stage that determines which North firm transfers the technology. In the following situation, however, our model and results still apply.[21] Two North firms, firms $N_1$ and $N_2$, have two different technologies and compete to transfer technology 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 one of the two technologies. Once one technology has been adopted, the other is redundant. Moreover, consumers regard the final good produced by firms $N_1$ and $N_2$ as homogeneous goods.[22] 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.[23] If firm $N_1$ can produce its intermediate good more cheaply than can firm $N_2$, then it can induce firm $S$ to 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 an $NN$ duopoly. In this case, the potential for technology transfer expands. It would be interesting to examine technology transfer with a general number of firms. However, in this general setting, entry–deterring technology transfer as well as tariff–jumping technology transfer would probably still arise.

The assumptions that the South always has a higher MC of production and cannot reverse engineer the intermediate product may be questionable. In fact, there have been substantial shifts of some types of manufacturing to the South, precisely because of the South's improved technical capabilities and its lower MCs. However, at least in the short run, our assumption seems reasonable.

## 7 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 that only a developed firm (from the North) can produce. Interestingly, not only tariff increases but also tariff reductions may lead to technology transfer. "Tariff–jumping" technology transfer may follow tariff increases, whereas "entry–deterring" technology transfer may be generated by tariff reductions. Although tariff–jumping technology transfer is somewhat similar to tariff–jumping FDI, entry–deterring technology transfer is specific to technology transfer. In particular, our policy implication that the South should adopt pro–competitive policies to facilitate technology transfer seems to be novel. Besides tariff reductions, pro–competitive policies include measures designed to lower, for example, the start–up costs of exporting.

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. Thus, our analysis of 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 foreclosing. However, with licensing, it may be difficult for the licensor to stop transferring technology once the licensee has the know–how. In our analysis, the North firm supplies the South firm with a key component, which the South firm cannot produce by itself. This may represent a substitute for more conventional technology transfer through licensing. However, this is a conceptually distinct phenomenon, and the phrase "technology supply" may be an alternative to the phrase "technology transfer" in the context of our paper.

Second, we can get rid of arguments about optimal licensing contracts. There are a number of variations in licensing contracts. In particular, the licensing literature has extensively compared between per unit royalties and fixed fees.

Third, we can examine the relationship between technology transfer and policies related to the intermediate good. Horiuchi and Ishikawa (2007) show that if the South subsidizes final–good production or imports of the intermediate good, although technology transfer is facilitated, the maximum welfare obtained under production or import subsidies is lower than that under imposing a tariff on the final good.

Finally, and more importantly, considering the intermediate–product market rather than the licensing market, we can particularly argue that North firms may have an incentive to transfer their technologies to South firms even if there is no licensing market, or a restricted market, in the South, which is the case in many developing countries.

# Appendix

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

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

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

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

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

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

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

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

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

In the three–firm oligopoly, firm $N_1$ offers firm $S$ the intermediate–good at a price that maximizes $\pi^{N_1}_{NSN}$, subject to $\pi^{S}_{NSN} \geq 0$. The constraint can be rewritten as $x^{S}_{NSN} \geq 0$ and hence

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

The $r$ that maximizes $\pi^{N_1}_{NSN}$ with no constraint is given by

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

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

By noting that

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

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 that $t_{SN} < \bar{t}$.

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

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

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

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

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

Given (23), $b - c^S - 4\sqrt{af_2} < 0$. In addition, noting that $c^S - c^N \leq b - c^N - (4/5)\sqrt{af_2}$, 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 $c^S \leq c^N + (b - c^N - (4/5)\sqrt{af_2})$.

# References


[1] Barba Navaretti, Giorgio and Anthony J. Venables, *Multinational Firms in the World Economy*, Princeton: Princeton University Press, 2004.

[2] Coe, David T., Elhanan Helpman, and Alexander W. Hoffmaister, "North–South R&D Spillovers," *Economic Journal* 107 (1997):134–149.

[3] Davies, Howard, "Technology Transfer through Commercial Transactions," *Journal of Industrial Economics* 26 (1977):161–175.

[4] Eswaran, Mukesh, "Licensees as Entry Barriers," *Canadian Journal of Economics* 27 (1994):673–688.

[5] Horiuchi, Eiji and Jota Ishikawa, "Tariffs and Technology Transfer through an Intermediate Product," COE–RES Discussion Paper Series, No.201(2007), Hitotsubashi University.

[6] Ishikawa, Jota, "Trade Liberalization and Technology Transfer through an Intermediate Product," *International Economy* 11 (2007):3–10.

[7] — and Eiji Horiuchi, "Strategic Technology Transfer through FDI in Vertically Related Markets," COE–RES Discussion Paper Series, No. 243 (2008), Hitotsubashi University.

[8] Kabiraj, Tarun and Sugata Marjit, "Protecting Consumers through Protection: The Role of Tariff–induced Technology Transfer," *European Economic Review* 47 (2003):113–124.

[9] Kamien, Morton and Yair Tauman, "Patent Licensing: The Inside Story," *Manchester School* 70 (2002):7–15.

[10] Lin, Ping and Kamal Saggi, "Incentives for Foreign Direct Investment under Imitation," *Canadian Journal of Economics* 32 (1999):1275–1298.

[11] Markusen, James R., *Multinational Firms and the Theory of International Trade*, Cambridge: MIT Press, 2002.

[12] Mukherjee, Arijit and Enrico Pennings, "Tariffs, Licensing and Market Structure," *European Economic Review* 50 (2006):1699–1707.

[13] Pack, Howard and Kamal Saggi, "Vertical Technology Transfer via International Outsourcing," *Journal of Development Economics* 65 (2001):389–415.

[14] Peck, Merton J. and Shuji Tamura, "Technology," in Patrick, Hugh and Henry Rosovsky (eds.), *Asia's New Giant: How the Japanese Economy Works*, Washington D.C.: Brookings Institution, 1976.

[15] Rockett, Katharine E., "Choosing the Competition and Patent Licensing," *RAND Journal of Economics* 21 (1990):161–171.

[16] Wang, X. Henly, "Fee versus Royalty Licensing in a Cournot Duopoly Model," *Economics Letters* 60 (1998):55–62.

## Notes

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

[2]Similar examples include a Malaysian car producer, Proton, established in 1983 and another Korean car producer, Samsung Motors, established in 1994. Mitsubishi Motors Co. and Nissan Motor Co., Ltd., respectively, provided technological assistance to Proton and Samsung.

[3]See, for example, Davies (1977) for the Indian case and Peck and Tamura (1976) for the Japanese case.

[4]See, for example, Markusen (2002) and Barba Navaretti and Venables (2004).

[5]For example, the Chinese government does not allow foreign car makers to have their own subsidiaries in China. They force foreign car makers to form JVs with local firms in order to accelerate technology transfer. In addition, foreign car makers must obtain Chinese government permission to form JVs, which is not easy.

[6]Pack and Saggi (2001) are concerned with technology transfer from the downstream sector to the upstream sector through outsourcing. Ishikawa and Horiuchi (2008) show that Pareto gains from technology spillover through FDI arise in vertically related markets.

[7]Eswaran (1994) shows that in the presence of a potential entrant, an incumbent may invite outsiders as licensees.

[8]The licensing literature has extensively compared per unit royalties and fixed fees. See, for example, Wang (1998) and Kamien and Tauman (2002).

[9]We assume away FDI by the North firms. Firms may refrain from FDI because of high setup costs or the high risk of expropriation, for example.

[10]For example, the firm may incur FCs to establish distribution networks in the South before commencing exports.

[11]For example, this could occur if firm $N_2$ incurs high FCs in exporting the intermediate good. See also Section 6.

[12]Using a nonlinear demand function does not materially affect our results.

[13]The tariff rates under which the $N$ monopoly is the initial equilibrium are set out later.

[14]Subscripts denote the final-good market's structure: $N$ ($S$) denotes the $N$ ($S$) monopoly; $NS$ ($NN$) denotes the duopoly between firms $N_1$ and $S$ ($N_1$ and $N_2$); and $NSN$ denotes the oligopoly among the three firms.

[15]The general form of equilibrium in the last stage is given in the appendix (equations (A1) to (A7)).

[16]$\widetilde{r}_{NS} < \overline{r}_{NS}$ holds with $b - c^N - t > 0$.

[17]A decrease in the tariff may lead to a negative tariff (i.e., an import subsidy), which our analysis allows for.

[18]The subscripts $SN$ is used to distinguish between the duopoly generated by a tariff reduction and the duopoly generated by a tariff increase.

[19]$r < 0$ does not necessarily imply that the acutal price of the intermediate good is negative, because the MC of producing the intermediate product is simply normalized to zero.

[20]The price of the final good rises monotonically with the tariff. In addition, $p_N(t) = p_{NS}(t)$ holds at $t_{NS}$.

[21]For details, see Ishikawa (2007), who extended the present model.

[22]Even if the final goods are differentiated, our results remain valid provided that they are close substitutes.

[23]Similar examples include plasma display panels compared to liquid crystal display panels in TV production and Blu-ray Discs relative to High-Definition Digital Versatile Discs in DVD-player production.

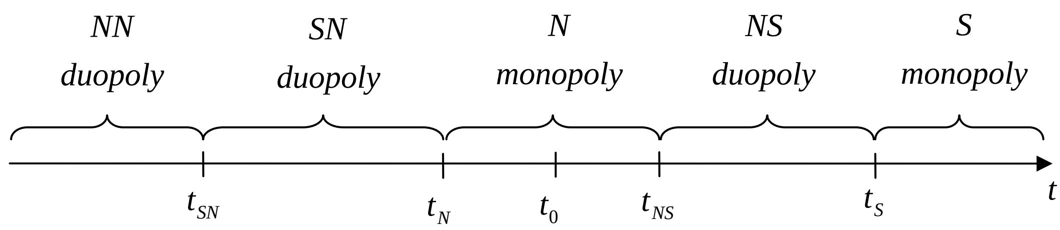
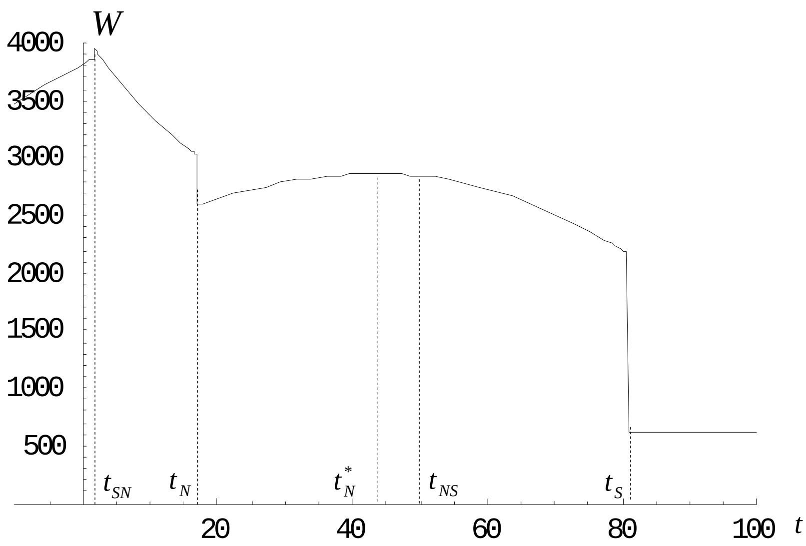


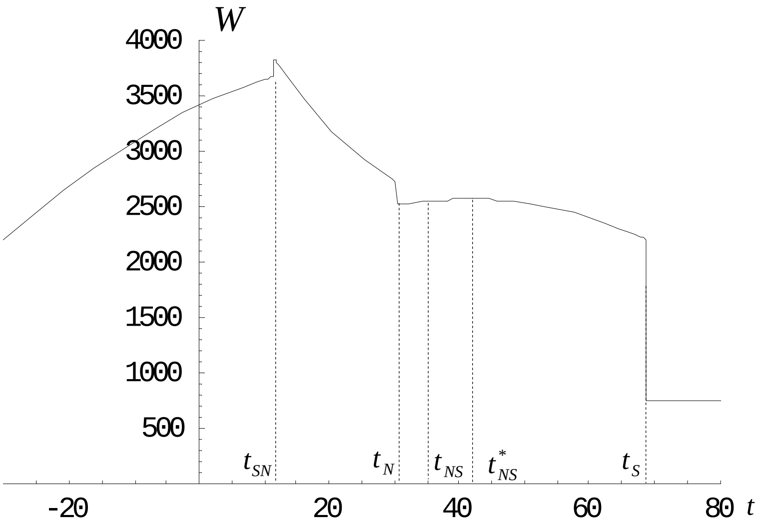

*Figure 1. Tariffs and market structures*




| $t_{SN}$ | $t_N$ | $t_{NS}$ | $t_S$ |
|---|---|---|---|
| 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 |

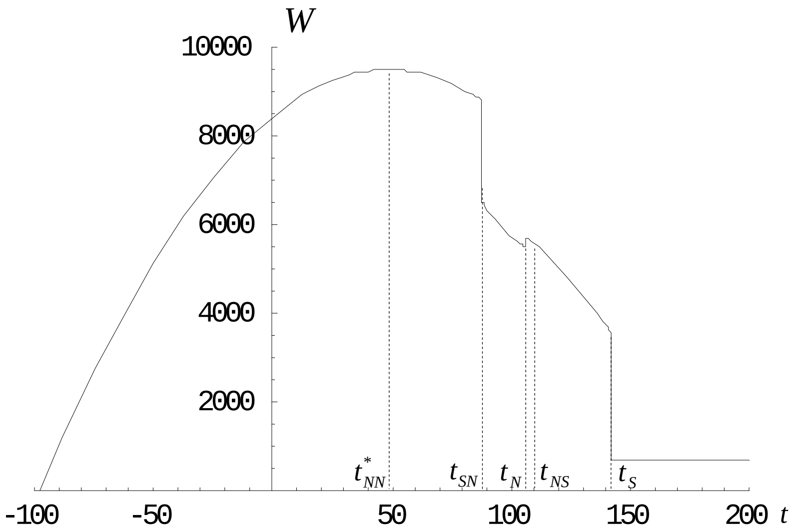
*Figure 2. Welfare-maximizing market structure: the SN duopoly* ($b + 2c^N - 3c^S \leq 0$)




| $t_{SN}$ | $t_N$ | $t_{NS}$ | $t_S$ |
|---|---|---|---|
| 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* ($b + 2c^N - 3c^S > 0$)




| $t_{SN}$ | $t_N$ | $t_{NS}$ | $t_S$ |
|---|---|---|---|
| 87.9 | 106.0 | 109.9 | 142.2 |

| $a$ | $b$ | $c^S$ | $c^N$ | $f_2$ |
|---|---|---|---|---|
| 1.0 | 200.0 | 115.0 | 5.1 | 879.0 |

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