Technology Licensing, Entry Mode and Trade Liberalization

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Abstract: In this paper, we first examine the entry mode choice of a multinational firm between exporting and FDI when the foreign firm licenses a superior technology to a host firm in the host market. We relax the conventional assumption that a licensor always use its licensed technology in production, the foreign licensor, however, may use its original technology in production after licensing. We find that a tariff reduction of host country may attract the foreign firm to FDI, while it may reduce all of the foreign firm's profit, host firm's profit and the host country's welfare. We also find that a tariff reduction to change the foreign firm's entry mode from FDI to exporting may generate a Pareto welfare-enhancing equilibrium.

Keywords: FDI; Technology licensing; Trade liberalization; Entry mode
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1. Introduction

Driven by the WTO's promotional efforts on trade liberalization, member countries of the WTO around the world have reduced or eliminated trade protectionism measures such as quotas and tariffs. Moreover, these countries have also increasingly opened up their markets to multinational enterprises for business or investing. In addition to serving the host countries by exports, multinational firms may choose to locate their factories there through direct foreign investment (FDI), acquire foreign companies and form a joint venture with host firms, or license their superior cost-effective technologies to host firms that use relatively less efficient technologies in production. Despite that there are different modes of serving markets in the host countries, we focus our analysis on exporting and FDI with the presence of international technology licensing.

The financial benefits of technology licensing are well-documented. For example, Nadiri (1993) indicates that revenues from technology licensing in British and France from 1970 to 1988 grew at an astonishing rate of 400%, while the United States and France the technology licensing revenues grew at a rate of up to 550%. Vishwasrao (2007) finds that U.S. companies in 2002 received up to $12,075 million dollars from licensing their superior technologies to foreign independent firms. These results also suggest that cross-border technology licensing constitutes an effective and profitable way for international enterprises to enter host country markets. The issues on international or multinational technology licensing has become the focal point of research.

Considerable contributions have been made in explaining the economic determinants of exporting versus FDI. Among the important economic determinants are the advantages of low-cost inputs in host countries, the disadvantage of high trade costs, the tariff-jumping arguments for FDI, the growing market size and demand that induce FDI vs. exports, the advantage of opening up local markets for attracting superior technology transfers from multinational firms, and the importance of working as mechanism to smooth demand volatility in the host country markets.[1] Helpman (2006) presents a systematic review of the literature concerning how trade and investment affects the organizational forms of international firms in serving foreign markets. Mukherjee and Sinha (2007) show that a host country's welfare may be negatively affected by a change in foreign entry mode from FDI to exporting when the host country's market size is small and the domestic production cost decreases. Horiuchi and Ishikawa (2009) present a North-South model of trade and technology transfer when technology is embodied in an intermediate product that only North firms can produce. The authors show that North firms may have an incentive to transfer their technologies to South firms despite the imperfectness of the South's licensing market. The authors further suggest the implementation of pro-competitive policies by the government in the South for inducing technology transfer and enhancing welfare. Focusing on the scenario where a foreign firm licenses its superior technology and decides on its mode of entry into the host country market, a recent contribution by Sinha (2010) examines how international licensing affects the host country welfare.[2] The author shows that welfare effect can be negative depending on the fee structure of strategic licensing.

The objective of this paper is twofold. First, we present a duopolistic competition model to examine the entry choice of a multinational firm when the firm licenses a superior technology to its competitor in the host country market. Second, we use the model to examine the host

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[1]See, for example, Caves (1971), Buckley and Casson (1981), Lipsey and Weiss (1984), Horstmann and Markusen, (1987, 1996), Motta (1992), Ethier and Markusen (1996), Blonigen (2001), Qiu and Tao (2001), Rob and Vettas (2003), Bernard and Jensen (2004), Helpman, Melitz, and Yeaple (2004), Mukherjee and Sinha (2007), Chang and Gayle (2009), Mukherjee and Suetrong (2009), and Sinha (2010).

[2] Studies on intra-industry licensing under imperfect competition include Wang(1998), Wang and Yang (1999), Wang (2002), Kamien and Tauman (2002), Fosfuri and Roca (2004) , Liao and Sen (2005), Sen and Tauman (2007), and Poddar and Sinha (2010).

country's trade liberalization policy through tariff reduction to see how it affects the foreign firm's entry mode choice. As in Sinha (2010), we examine the two important modes of entry: exporting and FDI, in the present of international technology licensing. But our paper differs from his contribution in two aspects. First, Sinha (2010) examines the determination of a socially optimal tariff for the host country government. In our paper, we focus the analysis on issues related to trade liberalization through gradual adjustments in import tariffs and treat tariffs as exogenous. Second, we examine the scenario where a multinational enterprise as a producer and licensor may use the original technology in its production for increasing licensing revenue and total profit. This strategy relaxes the conventional assumption that a producer/licenser must always use its licensed technology in production. As the Ford Declared that they will begin to sell hybrid Escape in 2015, which is equipped with a hybrid car battery licensed by TOYATA, whereas, Toyota RAV4 which is a rival vehicle produced by Toyota is not unequipped with such a licensed device. Thus, we are curious about what's the motivation behind such a licensing strategy. By considering such a licensing strategy, we find that in the exporting mode, if the tariff rate is low, the foreign firm grants royalty-rate licensing and uses its superior technology in production. If the tariff rate is high, the foreign firm grants fixed-fee licensing but uses the original technology in production. We show the conditions under which tariff reduction changes the entry mode from exporting to FDI and results in a Pareto welfare-deteriorating trade equilibrium. We further identify the circumstances when tariff reduction changes the entry mode from FDI to exporting and generates a Pareto welfare-enhancing trade equilibrium.

The remainder of the paper proceeds as follows. In Section 2, we first present an analytical framework of entry modes for a foreign firm to serve the host country by exporting or FDI. We then discuss foreign and home profit functions under different structure of licensing fees when the foreign firm may or may not use its licensed technology in production. In Section 3, we analyze the foreign firm's optimal decision in choosing its entry mode between exporting and FDI. Section 4 examines economic effects of the home country's trade liberalization policy through tariff reductions. Concluding remarks can be found in Section 5.

2. The Analytical Framework

2.1 *The basic assumptions*

A foreign firm (denoted as firm 1) possessing an advanced production technology (hereafter as "superior") decides on serving a host country market by exporting or by FDI, and competes with a domestic firm (denoted as firm 2) in a Cournot fashion in the host country. The demand function of the host market is $p = a - (q_1 + q_2)$, where p is the market price, and q_1 and q_2 are the output produced by firm 1 and firm 2, respectively. Both of the foreign and domestic firms' marginal production cost with a "generic" technology is c. The foreign firm had gotten a superior technology which can reduce an amount of ε for per unit cost of output. If the foreign firm produced with the superior technology, then its marginal cost of production, $c - \varepsilon$, where $\varepsilon \in [0, \varepsilon]$ represents the cost-saving level of per unit product. The foreign firm can license this superior technology by a two-part tariff contract.

In the licensing contract, the foreign firm states clearly weather or not he will use its own licensed technology to produce after the superior technology is licensed. Thus, the licensing contract can be represented by $\{r, f, U\}$, where r is the royalty rate, f is the fixed-fee and $U \in \{Y, D\}$ is the state that weather he will use the superior to produce after licensing, if $U = Y$ (D) represents firm 1 uses (does not use) the superior technology after licensing. Increase such a degree of freedom to the licensing contract is to depict the real case and highlight the possibility that not to use its own superior technology may constitute a better strategy for the licensing firm than to use. This is quite different from the traditional assumption that a prouder/licenser must always use its licensed technology after licensing and is more general than previous literature.

As for the two entry mode, if the foreign firm chooses exporting, it has to pay a specific tariff t on his product to the host country; on the contrary, if chooses FDI, it can avoid the tariff payments but has to incur a start-up cost, denoted as $G(>0)$. We will examine the choice of the foreign firm between exporting and FDI when the firm want to license its superior technology to the host firm.

The notations of the paper are as follows: *EY* (*FY*) represents firm 1 chooses exporting (FDI) and adopts the superior technology in production after firm 1 licenses its superior technology to firm 2, *ED* (FD) represents firm 1 chooses exporting (FDI) but adopts the generic technology after licensing, and *EN* (*FN*) represents firm 1 adopts exporting (FDI) but does not license to firm 2. Based on the afore-mentioned assumptions, the foreign has two entry modes (exporting and FDI) with three types of licensing contracts to choose. In the exporting mode, the foreign firm should pays a specific tariff, t, for its exports, its profit for each of the three types, {*EY*, *ED*, *EN*}, are given, respectively, as[3]

$$\pi_1^{EY} = (a - q_1 - q_2)q_1 - (t + c - \varepsilon)q_1 + rq_2 + f; \tag{1}$$

$$\pi_1^{ED} = (a - q_1 - q_2)q_1 - (t + c)q_1 + rq_2 + f; \tag{2}$$

$$\pi_1^{EN} = (a - q_1 - q_2)q_1 - (t + c - \varepsilon)q_1. \tag{3}$$

[3] When firm 1 does not license its superior technology, using the superior technology in production will dominate not using since the former causes a lower marginal cost.

The welfare of the host country is taken to be the sum of consumer surplus, CS, firm 2's profit, and tariff revenue. That is,

$$SW^{E} = CS^{E} + \pi_1^{E} + tq_1, \tag{4}$$

When the foreign firm serves the host country market by FDI, it does not need to pay tariffs but need to bear a fixed cost G, its profit for each of the three cases, {*FY*, *FD*, *FN*}, are given, respectively, as

$$\pi_1^{FY} = (a - q_1 - q_2)q_1 - (c - \varepsilon)q_1 + rq_2 + f - G; \tag{5}$$

$$\pi_1^{FD} = (a - q_1 - q_2)q_1 - cq_1 + rq_2 + f - G; \tag{6}$$

$$\pi_1^{FN} = (a - q_1 - q_2)q_1 - (c - \varepsilon)q_1 - G. \tag{7}$$

The host country welfare in the FDI mode is simply the sum of consumer surplus and firm 2's profit. That is,

$$SW^{F} = CS^{F} + \pi^{F} \tag{8}$$

If firm 2 is granted a license of firm 1's superior technology, its profit function is

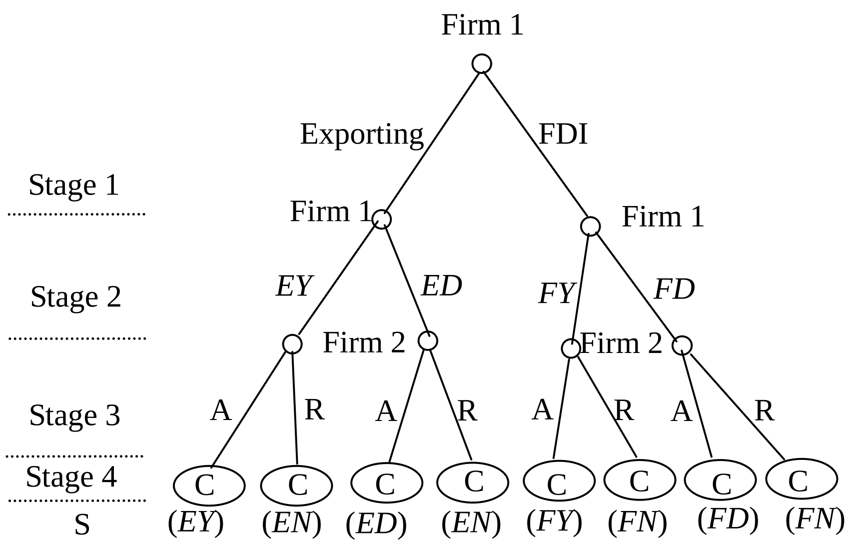
$$\pi_2^{L} = (a - q_1 - q_2)q_2 - (c - \varepsilon + r)q_1 - f \tag{9}$$

Regardless of firm 1's entry mode, firm 2's profit in the absence of technology licensing is

$$\pi_2^{N} = (a - q_1 - q_2)q_2 - cq_2, \tag{10}$$

Based on the above settings, the analysis involves a four-stage game as illustrated in Figure 1. In stage one, foreign firm 1 chooses between exporting and FDI to enter the host market. In stages two, given the entry mode chosen in stage 1, firm 1 determines an optimal licensing contract. In stage three, host firm 2 decides whether or not to accept licensing contract offered by firm 1. In stage four, the two firms play Counrot competition in the host market.

Because we want to discuss the welfare effects of trade liberalization, we treat tariff rate as exogenous, and use backward induction to solve the Nash sub-game perfect equilibrium.



EY(ED): Firm 1 chooses exporting, licensing, and using (not using) the licensed technology.
FY(FD): Firm 1 chooses FDI, licensing, and using (not using) the licensed technology.
EN(FN): Firm 1 chooses (or FDI) with no licensing
A(R): Firm 2 agrees (reject) firm 1's licensing contract
C: Cournot Competition
S: Sub-game perfect equilibrium

Figure 1. *Game tree*

3. Optimal Entry Mode Choice between Exporting and FDI

In this section, we will derive the market equilibrium and the optimal license contract of the foreign firm when it chooses exporting and FDI to enter the host market, respectively. We then compare the foreign firm's profit between the SPE of exporting and FDI mode to determine its optimal entry mode. It is instructive to follow the game tree in Figure 1 to solve different subgames.

3.1 *Licensing Contract when the entry mode is exporting*

In this subsection, , we will resolve the optimal two-part tariff of using and not using the superior technology after licensing contract , respectively, , and then find out the optimal licensing contract for different tariff rate t in the exporting mode.

3.1 (a) ***Using the superior technology to produce after licensing (the EY subgame)***

In this subgame, firm 1 offers a licensing contract $\{r, f, Y\}$ to firm 2, thus, the profit functions of the two firms are given by equations (1) and (9), respectively. Deriving the first-order conditions for the two equations, we solve for the Nash equilibrium outputs as $q_1 = \dfrac{a-c+\varepsilon+r-2t}{3}$ and $q_2 = \dfrac{a-c+\varepsilon-2r+t}{3}$. Substituting these equilibrium output into (1) and (9) yields :

$$\pi_1^{EY} = \frac{(a-c+\varepsilon+r-2t)^2}{9} + r\frac{(a-c+\varepsilon-2r+t)}{3} + f, \tag{11}$$

$$\pi_2^{EL} = \frac{(a-c+\varepsilon-2r+t)^2}{9} - f. \tag{12}$$

Firm 2 will accept the licensing contract offered by firm 1 if $\pi_2^{EL} - f \geq \pi_2^{EN}$,[4] which implies that

$$f \leq \frac{(a-c+\varepsilon-2r+t)^2}{9} - \frac{(a-c-\varepsilon+t)^2}{9}. \tag{13}$$

Substituting (13) into the profit functions in (11), the profit of firm 1 can be written as.

$$\pi_1^{EY} = \frac{(a-c+\varepsilon+r-2t)^2}{9} + r\frac{(a-c+\varepsilon-2r+t)}{3} + \frac{(a-c+\varepsilon-2r+t)^2}{9} - \frac{(a-c-\varepsilon+t)^2}{9}, \tag{14}$$

Taking the first-order derivative of (14) with respect to r, we have $\dfrac{d\pi_1^{EY}}{dr} = \dfrac{(a-c+\varepsilon-2r-5t)}{9}$.

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[4] By the FOCs of (3) and (10), we have $q_1 = \dfrac{a-2(c-\varepsilon+t)+c}{3}$, $q_2 = \dfrac{a-2c+c-\varepsilon+t}{3}$ and $\pi_2^{EN} = \dfrac{(a-c-\varepsilon+t)^2}{9}$.

Evaluating this derivative at the points where $r = 0$ and $r = \varepsilon$, we have

$$\frac{d\pi_1^{EY}}{dr}\Big|_{r=0} = \frac{a-c+\varepsilon-5t}{9} \quad \text{and} \quad \frac{d\pi_1^{EY}}{dr}\Big|_{r=\varepsilon} = \frac{a-c-\varepsilon-5t}{9}. \tag{15}$$

Because $\frac{d^2\pi_1^{EY}}{dr^2} = \frac{-2}{9} < 0$ and $0 \le r \le \varepsilon$, we use the signs of (15) to determine the structure of the licensing contract as follows:

<u>Case 1</u>: $a-c+\varepsilon-5t<0$ (i.e., $t>\frac{a-c+\varepsilon}{5}$)

In this case, the best strategy for the licensor is to set $r = 0$. Substituting $r = 0$ into (13), we find that $f > 0$. It follows that fixed-fee licensing constitutes the optimal contract. Substituting $r = 0$ into (14) yields the equilibrium profit for firm 1 as

$$\pi_1^{EYf} = \frac{(a-c+\varepsilon-2t)^2 + 4\varepsilon(a-c+t)}{9},$$

where the superscript *EYf* represents the case when firm 1 adopts exporting and offers a contract of fixed-fee with using superior technology after licensing

<u>Case 2</u>: $a-c-\varepsilon-5t<0$ and $a-c+\varepsilon-5t>0$ (i.e., $\frac{a-c-\varepsilon}{5} < t < \frac{a-c+\varepsilon}{5}$)

In this case, the optimal royalty rate is an interior solution. Letting $\frac{d\pi_1^{EY}}{dr}$ to be zero, we solve for the optimal royalty as $r = \frac{a-c+\varepsilon-5t}{2}$. It is obvious that $f > 0$ from (13), thus, the optimal licensing contract involves a mixture of royalty-rate and fixed-fee licensing. Substituting $r = \frac{a-c+\varepsilon-5t}{2}$ into (14) yields the equilibrium profit for firm 1 as

$$\pi_1^{EYm} = \frac{(a-c+\varepsilon-t)^2 + 4t^2}{4} - \frac{(a-c-\varepsilon+t)^2}{9},$$

where the superscript *EYm* represents the case when firm 1 adopts exporting and offers a contract of two-part tariffs with using superior technology after licensing.

Case 3: $a-c-\varepsilon-5t>0$ (i.e., $t<\frac{a-c-\varepsilon}{5}$)

In this case, the best strategy is to set $r=\varepsilon$ without charging a fixed fee, i.e., $f=0$. Substituting $r=\varepsilon$ into (14) yields the equilibrium profit for firm 1 as

$$\pi_1^{EYr}=\frac{(a-c+2\varepsilon-2t)^2}{9}+\varepsilon\frac{(a-c-\varepsilon+t)}{3},$$

where the superscript *EYr* represents the case when firm 1 adopts exporting and offers a contract of royalty rate with using superior technology after licensing.

We summarize firm 1's profit function for all the relevant tariff rates as

$$\pi_1^{EY}(t)=\begin{cases}\pi_1^{EYr}(t)=\dfrac{(a-c+2\varepsilon-2t)^2}{9}+\varepsilon\dfrac{(a-c-\varepsilon+t)}{3} \\ \pi_1^{EYm}(t)=\dfrac{(a-c+\varepsilon-t)^2+4t^2}{4}-\dfrac{(a-c-\varepsilon+t)^2}{9} \\ \pi_1^{EYf}(t)=\dfrac{(a-c+\varepsilon-2t)^2+4\varepsilon(a-c+t)}{9}\end{cases}\text{ if }\begin{cases}t\le t_1^Y\equiv\dfrac{a-c-\varepsilon}{5} \\ t_1^Y\equiv\dfrac{a-c-\varepsilon}{5}\le t\le t_2^Y\equiv\dfrac{a-c+\varepsilon}{5} \\ t_2^Y\equiv\dfrac{a-c+\varepsilon}{5}\le t\le\bar{t}^Y\equiv\dfrac{a-c+\varepsilon}{2}\end{cases}. \quad (16)$$

The results of the above analysis lead to Lemma 1:

Lemma 1*: In the exporting mode, if the licensing contract is that the foreign firm use superior technology after licensing, the optimal fee stricture is fixed-fee (mixed, royalty-rate) licensing when the tariff rate is high (medium, low). The foreign firm's profit decreases with the tariff rate.*

Tariff rates determine the marginal cost differential between foreign and domestic firms when the foreign firm uses a superior technology in producing its product exports. When tariff rates in the host country is high (medium) (low), then the marginal cost differential is high (medium) (low), it more profitable to offer a fixed-fee (mixed) (royalty-rate) licensing. This is consistent with that in Sinha(2010). As the tariff rate goes down, the foreign firm become more competitive, than its total profit including production profit and licensing revenue will go up.

3.1(b) ***Using the generic technology to produce after licensing (the ED subgame)***

In this subgame, firm 1 offers a licensing contract $\{r, f, D\}$ to firm 2, thus, the profit functions of the foreign and home firms are given by π_1^{ED} in (2) and π_2^{EL} in (9). This is the case that firm 1 will not use its superior technology after licensing. Deriving the FOCs for the two firms, we solve for the Nash equilibrium outputs as $q_1 = \frac{a-c-\varepsilon+r-2t}{3}$ and $q_2 = \frac{a-c+2\varepsilon-2r+t}{3}$. Substituting these output equations back into the profit functions in (2) and (9) yields the firms' profits as

$$\pi_1^{ED} = \frac{(a-c-\varepsilon+r-2t)^2}{9} + r\frac{(a-c+2\varepsilon-2r+t)}{3} + f, \tag{17}$$

$$\pi_2^{EL} = \frac{(a-c+2\varepsilon-2r+t)^2}{9} - f. \tag{18}$$

Firm 2 will accept a license of the superior technology offered by firm 1 if the licensing contract is such that $\pi_2^{EL} - f \geq \pi_2^{EN}$. This implies that

$$f \leq \frac{(a-c+2\varepsilon-2r+t)^2}{9} - \frac{(a-c-\varepsilon+t)^2}{9}. \tag{19}$$

Despite that its superior technology is licensed to firm 2, firm 1 chooses to use the generic technology in producing its product for export. It follows from (19) that for the fixed fee to be zero, the royalty rate should is $r = \frac{3}{2}\varepsilon > 0$. This is because using the superior technology is a dominant strategy for firm 1 when firm 2 does not accept the licensing contract, thus firm 2 can only get π_2^{EN} even firm 1 offers a contract that he does not use the superior technology after licensing. Thus, the upper limit royalty rate that makes firm 2 accepting the contract is $r = \frac{3}{2}\varepsilon$ (i.e, $\pi_2^{EL} = \pi_2^{EN}$).

Substituting (19) into (17) and (18), we have the firms' profits as

$$\pi_1^{ED} = \frac{(a-c-\varepsilon+r-2t)^2}{9} + r\frac{(a-c+2\varepsilon-2r+t)}{3} + \frac{(a-c+2\varepsilon-2r+t)^2}{9} - \frac{(a-c-\varepsilon+t)^2}{9}, \quad (20)$$

$$\pi_2^{EL} = \frac{(a-c-\varepsilon+t)^2}{9}. \quad (21)$$

Taking the first-order derivative of the profit function in (20) with respect to r yields

$$\frac{d\pi_1^{ED}}{dr} = \frac{(a-c-4\varepsilon-2r-5t)}{9}. \quad (22)$$

Because $\frac{d^2\pi_1^{ED}}{dr^2} < 0$ and $0 \le r \le \frac{3}{2}\varepsilon$, we can proceeds as before by (22) to get the profit function of firm 1 in the ED subgame as follows

$$\pi_1^{ED}(t) = \begin{cases} \pi_1^{EDr}(t) = \frac{(2a-2c+\varepsilon-4t)^2}{36} + \varepsilon\frac{(a-c-\varepsilon+t)}{2} \\ \pi_1^{EDm}(t) = \frac{(a-c-2\varepsilon-3t)^2}{4} + (\varepsilon+t)(a-c-t) - \frac{(a-c-\varepsilon+t)^2}{9} \\ \pi_1^{EDf}(t) = \frac{(a-c-\varepsilon-2t)^2}{9} + \frac{(a-c+2\varepsilon+t)^2}{9} - \frac{(a-c-\varepsilon+t)^2}{9} \end{cases} \text{if} \begin{cases} 0 \le t \le t_1^D \equiv \frac{a-c-7\varepsilon}{5} \\ t_1^D \le t \le t_2^D \equiv \frac{a-c-4\varepsilon}{5} \\ t_2^D \le t \le \bar{t}_D \equiv \frac{a-c-\varepsilon}{2} \end{cases} \quad (23)$$

To simply the analysis, we confine the tariff rate to be positive and the host market is always a duopoly market. From (23), we can see that, for a small $\varepsilon \in (0, \frac{a-c}{7}]$, $t_1^D > 0$, thus, within the three relevant ranges of tariff rate $0 \le t \le t_1^D$, $t_1^D \le t \le t_2^D$, and $t_2^D \le t \le \bar{t}^D$, the foreign firm will offer a contract of royalty-rate, two-part tariff and fixed-free. For a medium ε $\varepsilon \in (\frac{a-c}{7}, \frac{a-c}{4}]$, then $t_1^D < 0$ but $t_2^D > 0$. In this case, only on tariff rate ranges $0 \le t \le t_2^D$ and $t_2^D \le t \le \bar{t}^D$ the foreign firm offer a contract of two-part tariff and fixed-free, respectively. For a large $\varepsilon \in (\frac{a-c}{4}, a-c]$, then $t_1^D < 0$ and $t_2^D < 0$. In this case, on tariff rate range $0 \le t \le \bar{t}^D$, the foreign firm will offer a contract of fixed-free.

Based on the results of the above analyses, we have

Lemma 2. *In the exporting mode, if the licensing contract is that the foreign firm the foreign firm uses the generic technology after licensing, the equilibrium foreign profit is a convex function of the tariff rate. For $\varepsilon \in (0, \frac{a-c}{7}]$, the foreign firm offers a royalty-rate (two-part, fixed-fee) licensing if the tariff rate is low (medium) (high). For $\varepsilon \in (\frac{a-c}{7}, \frac{a-c}{4}]$ the foreign firm offers mixed (fixed-fee) licensing if the tariff rate is low (high). For $\varepsilon \in (\frac{a-c}{4}, a-c]$ the foreign firm only offers fixed-fee licensing for any positive tariff.*

Lemma 2 indicates how the structure of licensing contract is affected by tariff rate when the foreign firm adopts export and sign a license contract that he will use the generic technology after licensing.

Based on Lemma 1 and Lemma 2, we further derive the sub-game perfect equilibrium license contract $\{r, f, U\}$ for the exporting mode for a given tariff rate. Given a tariff rate, we wish to compare equilibrium profits for the foreign firm when it chooses between using the superior technology (i.e. $U = Y$) and using generic technology (i.e. $U = Y$) to produce after licensing. Because $t_1^D < t_2^D < t_1^Y < t_2^Y$ with a upper limit of the tariff rate $\bar{t} = \min(\bar{t}^Y, \bar{t}^D) = \bar{t}^D = \frac{a-c-\varepsilon}{2}$ to assure a duopoly market.

By Lemmas 1 and 2 and using (16) , (23) to compare the profit of firm 1 between EY and ED, we have subgame equilibrium of exporting.(proof referred to the max appendix)

$$\pi_1^E(t)=\begin{cases}\pi_1^{EYr}(t)=\dfrac{(a-c+2\varepsilon-2t)^2}{9}+\varepsilon\dfrac{(a-c-\varepsilon+t)}{3} \\ \pi_1^{EDf}(t)=\dfrac{(a-c-\varepsilon-2t)^2}{9}+\dfrac{(a-c+2\varepsilon+t)^2}{9}-\dfrac{(a-c-\varepsilon+t)^2}{9}\end{cases} \text{if } \begin{cases}0\le t\le t_1^Y\equiv t^S\equiv\dfrac{a-c-\varepsilon}{5} \\ t^S\le t\le \bar{t}\equiv\dfrac{a-c-\varepsilon}{2}\end{cases} \quad (24)$$

It follows that we have the first proposition:

Proposition 1. *In the exporting mode, if tariff rate is low, the foreign firm will license to the host firm by a* $\{\varepsilon,0,Y\}$ *contract , whereas, if tariff rate is high, the foreign firm will license to the host firm by a* $\{0,f,D\}$ *contract. (See Appendix for the proof).*

Proposition 1 tells us that when the tariff rate is low, the contract of using the superior technology after licensing with a royalty fee is more profitable for firm 1; otherwise, if the tariff rate is high, the contract of not using the superior technology after licensing with a fixed fee is better.

3.2 *Licensing contract when the entry mode is FDI*

Under the entry mode of FDI, the foreign firm needs not to pay any tariffs ($t=0$) but incurs a start-up cost G (>0). This start-up cost does not affect the structure of the licensing contract. As a result, foreign firm's profit in the FDI mode can be measured by its profit in the exporting mode at zero tariff rate, minus the start-up cost. Substituting $t=0$ into the foreign profit function in (23) and subtracting G yields

$$\pi_1^F=\pi_1^{EYr}(0)-G=\frac{(a-c+2\varepsilon)^2}{9}+\varepsilon\frac{(a-c-\varepsilon)}{3}-G \quad (25)$$

From (25), we have

Proposition 2. *When the entry mode is FDI, the foreign firm will license to the host firm by a* $\{\varepsilon,0,Y\}$ *contract.*

3.3 *The foreign firm's optimal entry mode*

We are now examine the entry choice of firm 1 between exporting and FDI , as well as the associate licensing contract. To find out the subgame perfect equilibrium, we first draw the line of firm 1's profits function of the exporting mode in Figure 3, and then put the line of firm 1's profits function of FDI mode (by (26)) in the figure. By (25) , we can see that the profits line of the exporting mode is "U" on tariff rate, which has three types depending on the licensed technology's cost-effectiveness ε. Figure 3(i) represents the case of $\varepsilon \in (0, \frac{a-c}{6}]$, where t^m at which rate $\pi_1^{EDf}(t)$ in (25) is minimum is greater than the critical rate t^S at which tariff rate the licensing contract structure changes, and $\pi_1^{EDf}(\bar{t}) > \pi_1^{EDf}(t^S)$; Figure 3(ii) represents the case of $\varepsilon \in (\frac{a-c}{6}, \frac{2(a-c)}{7}]$, where $t^m > t^S$ but $\pi_1^{EDf}(\bar{t}) < \pi_1^{EDf}(t^S)$; Figure 3(iii) represents the case of $\varepsilon \in (\frac{2(a-c)}{7}, (a-c)]$, where $t^m < t^S$.[5] Furthermore, by (26), it's obvious that $\pi_1^F = \pi_1^{EYr}(0) - G$ is a horizontal line in Figure 3 and its height decreases with the set-up cost G.

In Figure 3 (i), we can see that, if $\pi_1^{EDf}(\bar{t}) < \pi_1^F < \pi_1^{EYr}(0)$ (*ex.* π_{10}^F), then for $t \in (t^c, \bar{t})$,

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[5] It follows from (17) that $\frac{d\pi_1^{EYr}}{dt}|_{t_1^Y} < 0.$ From equation (25), we also know that $\frac{d\pi_1^{EDf}}{dt}|_{t_1^Y} = \frac{-2[2(a-c)-7\varepsilon]}{15} > (=)(<)0$, for $\varepsilon > (=)(<)\frac{2(a-c)}{7}$. For $\varepsilon < \frac{2(a-c)}{7}$, the profit function π_1^{EDf} is an inverted-U shape between t_1^Y and $\bar{t}$ with a minimum value being equal to $t_m = \frac{2(a-c)-5\varepsilon}{4}$. When $t_m > (=)(<)\frac{t_1^Y + \bar{t}}{2}$, that is, for $\varepsilon < (=)(>)\frac{(a-c)}{6}$, we have $\pi_1^{EDf}(t_1^Y) < (=)(>)\pi_1^{EDf}(\bar{t})$. Summarizing these results, we have the three different cases of (i) $0 < \varepsilon < \frac{a-c}{6}$ (ii) $\frac{a-c}{6} < \varepsilon < \frac{2(c-c)}{7}$ and (iii) $\frac{2(c-c)}{7} < \varepsilon < a-c$ as illustrated in Figure 3.

the best entry mode for firm 1 is FDI with a $\{\varepsilon,0,Y\}$ licensing contract , and for $t\in(0,t^c)$, the best entry mode is exporting with a with a $\{\varepsilon,0,Y\}$ licensing contract, moreover, if the tariff rate goes down, the entry mode of firm 1 can only be changed from FDI to exporting; if $\pi_1^{EDf}(t^S)<\pi_1^F<\pi_1^{EDf}(\bar{t})$ (*ex.* π_{11}^F), then for $t\in(t_4^c,\bar{t})$, the best entry mode is exporting with a $\{0,f,D\}$ licensing contract; for $t\in(t_1^c,t_4^c)$, the best entry mode is FDI with a $\{\varepsilon,0,Y\}$ licensing contract; for $t\in(0,t_1^c)$, the best entry mode is exporting with a $\{\varepsilon,0,Y\}$ licensing contract, Thus, the full profit line is *luvp*; if $\pi_1^{EDf}(t^M)<\pi_1^F<\pi_1^{EDf}(t^S)$ (*ex.* π_{12}^F). then for $t\in(t_3^c,\bar{t})$, the best entry mode is exporting with a $\{0,f,D\}$ licensing contract; for $t\in(t_2^c,t_3^c)$, the best entry mode is FDI with a $\{\varepsilon,0,Y\}$ licensing contract; for $t\in(t^S,t_2^c)$, the best entry mode is exporting with a $\{0,f,D\}$; for $t\in(0,t^S)$, the best entry mode is exporting with a $\{\varepsilon,0,Y\}$ licensing contract, thus, the full profit line is *lmnp*. If $\pi_1^F<\pi_1^{EDf}(t^M)$ (*ex.* π_{13}^F), then for $t\in(t^S,\bar{t})$, the best entry mode is always exporting with a $\{0,f,D\}$ licensing contract; for $t\in(0,t^S)$, the best entry mode is exporting with a $\{\varepsilon,0,Y\}$ licensing contract. Thus, we can see an interesting phenomenon that if the tariff goes down from high level such as from $t\in(t_3^c,\bar{t})$ to $t\in(t_2^c,t_3^c)$ in *lmnp*, the entry mode of firm1 will switch from exporting to FDI, trade liberalization attracts FDI, which is contrary to the tradition wisdom of traditional tariff-jumping FDI. If $\pi_1^F<\pi_1^{EDf}(t^M)$ (i.e. the case that start-up cost is very high such as $\pi_1^F=\pi_{13}^F$), then the optimal entry mode is always exporting, regardless of the tariff rate . For cases (ii) and (iii) when $\frac{(a-c)}{6}<\varepsilon<\frac{2(a-c)}{7}$ and $\frac{2(a-c)}{7}<\varepsilon<a-c$, respectively, we have similar results as those in case (i).

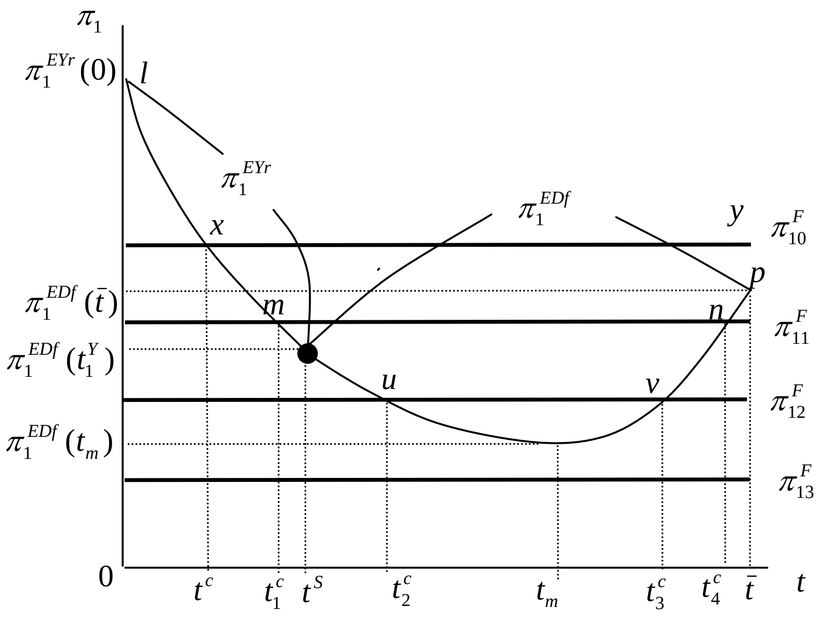

Figure 3(i). $0 < \varepsilon < \dfrac{(a-c)}{6}$

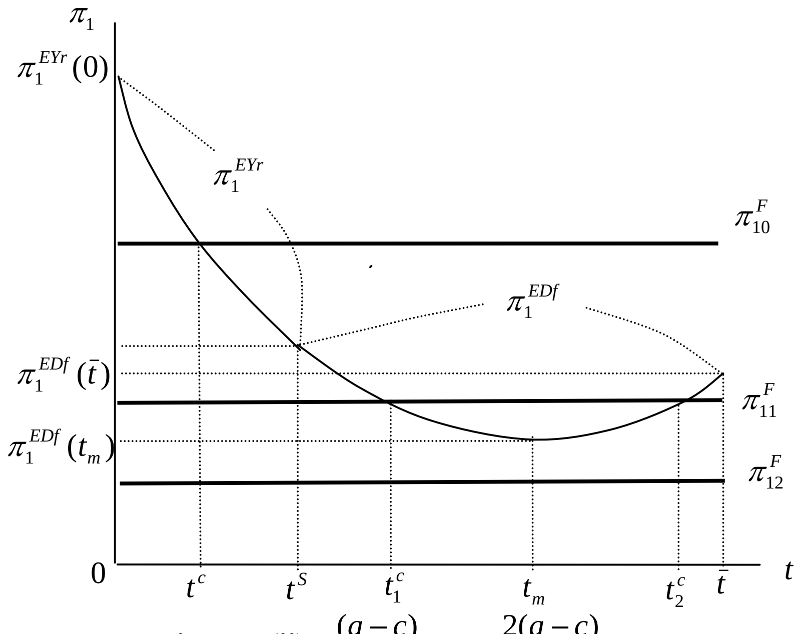

Figure 3(ii). $\dfrac{(a-c)}{6} < \varepsilon < \dfrac{2(a-c)}{7}$

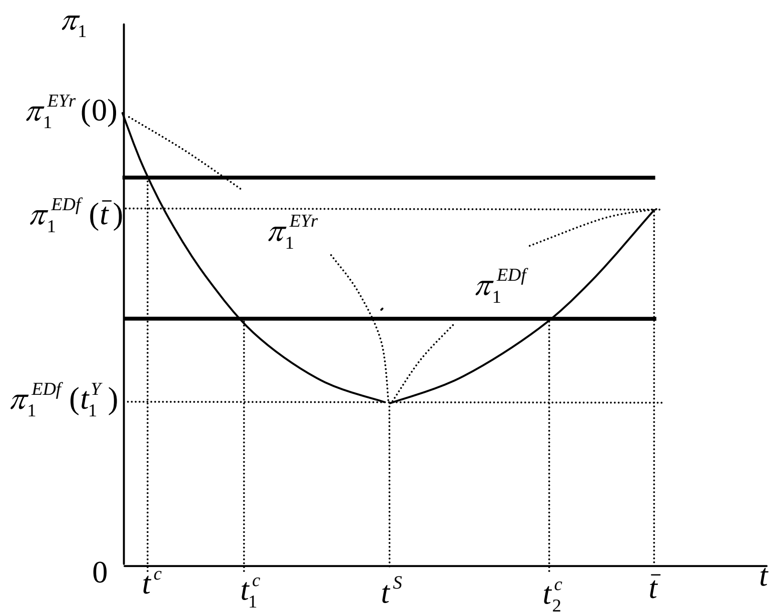

Figure 3(iii). $\frac{2(a-c)}{7} < \varepsilon < a-c$

We summarize the findings of the analysis in the following proposition:

PROPOSITION 3. *When considering the licensing contract of the two firms, (i) if the FDI's start-up cost is low and the tariff rate is high (low), the optimal entry mode is FDI (exporting). (ii) When the FDI's start-up cost is medium and the tariff rate is high (,medium, low), the optimal entry mode is exporting(FDI, exporting). (iii)When the FDI's start-up cost is significantly high, the optimal entry mode is exporting, regardless of the level of tariff rate.*

Proposition 3 has an interesting implication. When the FDI's start-up cost is medium and the tariff rate is high, the optimal entry mode is exporting. A reduction in tariff may change the foreign entry mode from exporting to FDI. This is because for a high tariff rate, the effective marginal cost of the foreign firm is very higher than that of the domestic firm's. In this case, profit including production and licensing revenue for the foreign firm is higher when it licenses to firm 2 with a fixed-fee with not using the superior technology to produce contract. This is because when the foreign firm grants fixed-fee licensing but uses the generic technology in production (that is, Df), there are two counter effects on foreign firm's profit due to that the decrease of tariff rate will reduce the marginal cost differential between the two firms . One is the positive effect of increase of its production profit, the other is the negative effect of decrease of licensing revenue. For the case that the tariff rate is significantly high, the negative effect dominates the positive effect so that foreign profit will decline. At this moment, changing entry mode to FDI can mitigate the negative effect on its profit. This explains why a decrease in tariff may instead change the foreign entry mode from exporting to FDI.

4. Welfare Effects of Trade liberalization through Tariff Reductions

In this section, we use the aforementioned results to examine how the host country's trade liberalization policy through tariff reduction affects the associate welfares.

4.1 *Trade liberalization on foreign firm's profit*

By Figure 3 and Proposition 3, we have that when the FDI's start-up cost is small, a reduction in tariff rate can only change the entry mode from FDI to exporting (such as the line lxy in Figure 3 (i)), thus the profit of the foreign will never been reduced. But if the start-up cost is medium, the tariff reduction from high level may attract the foreign firm from exporting to FDI , thus it may reduce the foreign firm's profit.

Lemma 3. *If the host country's tariff reduction attract the foreign firm from exporting to FDI, it will reduce the foreign firm's profit; otherwise. the tariff reduction will not reduce the foreign firm's profit.*

4.2 *Trade liberalization on host firms profit*

Because the host firm 2 can only get the profit in the absence of technology licensing, no matter which type of licensing contracts firm 1 offer, thus the domestic firm's profit for a given tariff rate when the foreign firm chooses the exporting mode is

$$\pi_2^E = \frac{(a-c-\varepsilon+t)^2}{9}. \tag{27}$$

If, instead, the foreign firm undertakes FDI, domestic profit is also identical to the one in (27) without tariff rate, the profit of the domestic firm is

$$\pi_2^F = \frac{(a-c-\varepsilon)^2}{9}. \tag{28}$$

Based on Figure 3 and Proposition 3, we find that the effect of changes in the tariff rate on the domestic profit has several possibilities. (i) If a decrease in tariff does not alter the exporting mode, the tariff reduction will reduce on domestic profit, which can be seen from equation (27). (ii) If a decrease in tariff does not alter the FDI mode, the tariff reduction decrease has no effect on domestic profit from (28). (iii) If a decrease in tariff changes the mode from exporting to FDI, domestic profit decreases from π_2^E to π_2^F. (iv) If a decrease in tariff change the foreign entry mode from FDI to exporting, domestic profit increases from π_2^F to π_2^E.

We thus have

Lemma 4. *When the host country's tariff reduction does not affect the foreign entry mode of exporting, domestic profit decreases. If the tariff reduction does not affect the foreign entry mode of FDI, domestic profit remains unchanged. If the tariff reduction changes the entry mode from exporting to FDI, domestic profit decreases. But if the tariff reduction changes the foreign entry mode from FDI to exporting, domestic profit increases.*

4.3 *Effects of trade liberalization on consumer surplus*

As shown in Proposition 1 for the exporting mode, if the tariff rate is relatively high, the foreign firm licenses to the host firm by a contact of fixed fee with using generic technology to produce after licensing. In this case, the equilibrium product of the foreign and domestic firms are $\frac{a-2(c+t)+c-\varepsilon}{3}$ and $\frac{a-2(c-\varepsilon)+c+t}{3}$, respectively, thus total product in the host market is $\frac{2a-2c+\varepsilon-t}{3}$. On the contrary, if the tariff rate is significantly low, the foreign firm licenses to the host firm by a contact of royalty-rate with using the superior technology to produce after licensing, in this situation, the equilibrium quantities of the good produced by the foreign and domestic firms become $\frac{a-2(c-\varepsilon+t)+c}{3}$ and $\frac{a-2c+c-\varepsilon+t}{3}$, respectively. The total production is $Q=\frac{2a-2c+\varepsilon-t}{3}$, which is the same as the previous case. Thus, consumer surplus in exporting mode is calculated as

$$CS^E=\frac{(Q^E)^2}{2}=\frac{(2a-2c+\varepsilon-t)^2}{18}. \tag{29}$$

In the FDI mode, the foreign firm grants a contract of royalty-rate licensing with using its superior to produce. The equilibrium quantities of the good produced by the two firms are $q_1^F=\frac{a-2(c-\varepsilon)+c}{3}$ and $q_2^F=\frac{a-2c+c-\varepsilon}{3}$, respectively. Thus, the total production is $Q^F=\frac{2a-2c+\varepsilon}{3}$ Consumer surplus in FDI mode is calculated as

$$CS^F=\frac{(2a-2c+\varepsilon)^2}{18}. \tag{30}$$

Based on Figure 3 and Proposition 3, the effect of tariff reductions on the host country's consumer surplus depends on the following conditions. (i) If a decrease in tariff does not affect the foreign entry mode of exporting, consumer surplus decreases by (29). (ii) if a decrease in tariff does not affect the foreign firm's entry mode of FDI, consumer surplus remains unchanged.

(iii) If a decrease in tariff changes the foreign entry mode from exporting to FDI, consumer surplus increases by a switch from (29) to (30). (iv) If a decrease in tariff changes the entry mode from FDI to exporting, consumer surplus decreases, this is because the foreign firm has to bear tariff and thus reduces its production, causing consumer surplus to decrease. We thus have

Lemma 5. *For the host country's trade liberalization policy through tariff reduction, if it does not affect the foreign entry mode of exporting (FDI), consumer surplus increases (remains unchanged). But if the foreign entry mode changes from exporting to FDI (from FDI to exporting), consumer surplus increases (decreases).*

4.4 *Effects of trade liberalization on the host country welfare*

To see how the overall welfare of the host country is affected by its trade liberalization through tariff reduction, it is necessary to examine how the decrease in tariff affects the foreign entry mode .

In the exporting mode, we have from Proposition 1 and equations (27) and (29) that the home country’s welfare function is:

$$SW^E = \begin{cases} SW^{EYr} = \frac{1}{2}(\frac{2a-2c+\varepsilon-t}{3})^2 + \frac{(a-c-\varepsilon+t)^2}{9} + t(\frac{a-c+2\varepsilon-2t}{3}) \\ SW^{EDf} = \frac{1}{2}(\frac{2a-2c+\varepsilon-t}{3})^2 + \frac{(a-c-\varepsilon+t)^2}{9} + t(\frac{a-c-\varepsilon-2t}{3}) \end{cases} \text{if } \begin{cases} t \le t^S \\ t \ge t^S \end{cases}. \quad (31)$$

In equation (31), the first term measures consumer surplus, the second term is the host firm's profit, the third term is tariff revenue.

In the FDI mode, the host country’s welfare only includes consumer surplus and the host firm's profit:

$$SW^F = \frac{1}{2}(\frac{2a-2c+\varepsilon}{3})^2 + \frac{(a-c-\varepsilon)^2}{9}. \quad (32)$$

It follows from (31) and (32) that, given the tariff rate t, consumer surplus is lower in the exporting mode than in the FDI mode. Nevertheless, domestic profit and tariff revenue are all greater in the exporting mode than in the FDI mode. Based on the welfare functions in (31) and (32), we use a graphical approach to demonstrate the welfare effect of tariff reduction. Because a tariff reduction may change the entry mode of firm 1, to analysis the effect of tariff reduction host welfare should take this into account. Figures 4(i), 4(ii), and 4(iii) illustrate three typical cases in terms of cost-effectiveness ε associated with the licensed technology. In each set of the diagrams, the upper panel depicts the foreign firm's profit while the lower panel depicts the home country's welfare, where SW^{EYr} (SW^{EDf}) represents the host welfare in firm 2's exporting mode with a licensing contract of royalty-rate (fixed-fee) and using superior (generic) technology to produce; whereas, SW^{F} represents the host welfare in firm 2's FDI mode. The three typical cases are as follows

(i) $0 < \varepsilon < \dfrac{2(a-c)}{19}$

This case is when the cost-saving level of superior technology is relatively small. It follows from Figure 4(i) that when the tariff rate is critically high (i.e., t is close to $\bar{t}$) relative to free trade (i.e. $t = 0$), the loss in consumer surplus due to the high tariff is less than offset by the gain in firm's profit and tariff revenue. As a result, the host country welfare is relatively higher under protected trade than under free trade. As can be seen in Figure 4(i), if foreign profit in the FDI mode is π_1^F , and in exporting mode is π_1^E which is $lmuq$, then the entry mode is exporting when $0 \le t \le t_1^c$; the entry mode is FDI when $t_1^c \le t \le t_2^c$; the entry mode is exporting when $t_2^c \le t \le \bar{t}$, thus the subgame perfect equilibrium profit of firm 1 is π_1 which is $lmnpq$. The corresponding welfare for the host country in the lower panel is $b\deg hijk$ (i.e. the thick line). Thus, the host country welfare decreases when there is a decrease in tariff is from the range $t_2^c \le t \le \bar{t}$ to the range $t_1^c \le t \le t_2^c$. In this case, the host firm's profit π_2 also decreases (as discussed in Lemma 4). We also see from Figure 4(i) that foreign profit decreases. Thus, trade liberalization through tariff reduction may be able to attract FDI, but causing a Pareto-inferior outcome in that the foreign firm, the host firm, and the host country are all worse off. The outcome is a "lose-lose-lose" equilibrium.

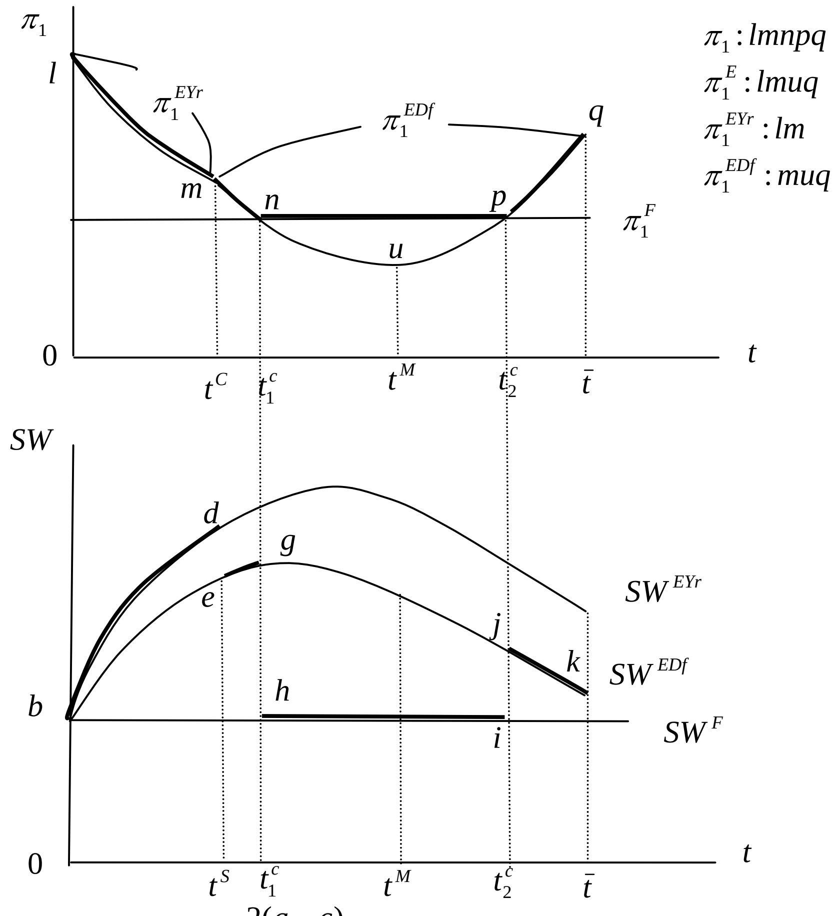

Figure 4 (i) $\varepsilon < \dfrac{2(a-c)}{19}$, $t^S < t^{EDf} < t^{EYr} < t^M < \bar{t} < t^J$

When the tariff rate decreases from the range $t_1^c \le t \le t_2^c$ to the range $0 < t \le t_1^c$, we have from Lemma 4 that domestic profit increases, foreign profit increases, and the host country welfare increases. Although trade liberalization through tariff reduction changes the entry mode from FDI to exporting, the outcome turns out to be a “win-win-win” equilibrium.

(ii) $\frac{(a-c)}{5} < \varepsilon < \frac{2(a-c)}{7}$

This case arises when the licensed technology's degree of cost-effectiveness ε is medium. If tariff rate is high (close to $\bar{t}$) relative to that under free trade ($t = 0$), the loss in consumer surplus due to the high tariff is not enough to compensate the increase in both the host firm's profit and the tariff revenue. This can easily be verified by (31) and (32) that $SW^{F} > SW^{EDf}(\bar{t})$ If foreign firm’s profit curve is $lmnpq$, the corresponding welfare curve for the host country is $b\deg hijk$. In this case, for a decrease in tariff rate is from the range $t_2^c \le t \le \bar{t}$ to the range $t_1^c \le t \le t_2^c$, the host country welfare increases. This is because the tariff reduction changes the foreign entry mode from exporting to FDI, causing the increase in consumer surplus to be less than the decrease in both the domestic profit and the tariff revenue. This explains why the host country welfare is positively affected by a decrease in tariff. If, instead, the foreign firm's profit curve is $lmn'p'q$, the corresponding welfare curve for the host country is $bd'e'g'h'i'j'k$. In this case, if a decrease in tariff rate changes the foreign entry mode from exporting to FDI, it may cause the host country welfare to decline.

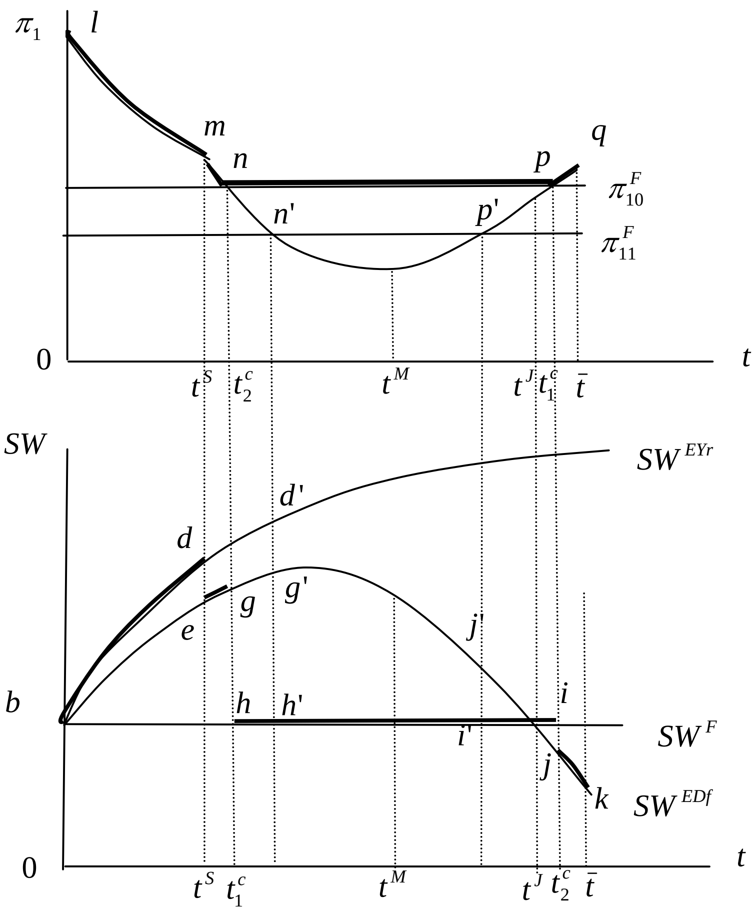

Figure 4 (ii) $\frac{(a-c)}{5} < \varepsilon < \frac{2(a-c)}{7}$, $t^S < t^{EDf} < t^m < t^J < \bar{t} < t^{EYr}$

(iii) $\frac{7(a-c)}{17} < \varepsilon < \frac{(a-c)}{2}$

This case arises when the licensed technology's degree of cost-effectiveness is high. The foreign firm’s profit curve is like $lmnpq$, the corresponding welfare curve for the host country is $bdhijk$. In this case, trade liberalization through tariff reduction that changes the foreign entry mode from exporting to FDI is always welfare-improving to the host country.

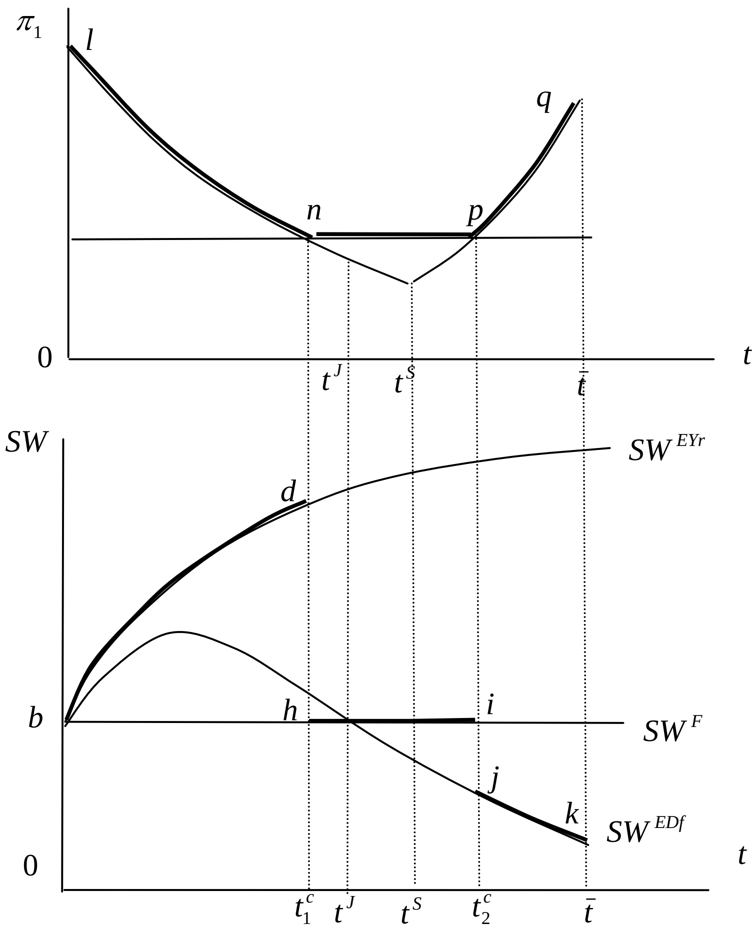

Figure 4 (iii) $\frac{7(a-c)}{17} < \varepsilon < \frac{(a-c)}{2}$, $t^m < t^{EDf} < t^J < t^S < \bar{t} < t^{EYr}$

We therefore have

PROPOSITION 4. *When the tariff reduction of the host country attracts FDI, then if the licensed technology's cost-effectiveness is not high enough, all of the foreign profit, domestic profit, and the host country's welfare may be reduced; if the licensed technology's cost-effectiveness is high enough, the foreign profit, domestic profit will be reduced and the host country's welfare be improved. When the tariff reduction of the host country causes a switch from FDI to exporting, then all of the foreign profit, domestic profit, and the host country's welfare may be improved.*

5. Concluding Remarks

In this paper, we examine the entry mode choice of a foreign firm among exporting and FDI to the host market when the foreign firm (the licensor) licenses a superior technology to its competitor (the licensee) in the host country market, while the foreign firm may strategically choose to use the original technology to produce after licensing which relaxes the conventional assumption that a licensing firm must always use the licensed technology in its own production.

Based on the simple analytical framework presented in this paper, we further analyze the host country's trade liberalization policy through tariff reduction to see how it affects the entry mode choice of a multinational firm between exporting and FDI in the presence of international technology licensing. We find that, in the exporting mode, if the specific tariff imposed by the host country government is low, the foreign firm's best strategy is to use its superior technology in production and charges a royalty rate in licensing. If the specific tariff is considerably high, however, the foreign firm's best strategy is to use the original technology rather than the licensed technology and charges a fixed license fee. When the cost saving of the licensed technology is not great if tariff reduction attracts FDI, it may results in a "lose-lose-lose" equilibrium (with a decrease in home and foreign profits as well as a deterioration in the host country welfare. We also identify the circumstances when tariff reduction changes the entry mode from FDI to exporting and generates in a "win-win-win" equilibrium (with an increase in home and foreign profits as well as an improvement in the host country welfare).

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Appendix

From (16), we can see that $\pi_1^{EY}(t)$ is continuous, convex and decreasing on t, because $\frac{d\pi_1^{EYr}}{dt}\Big|_{t\to t_1^{Y-}} = \frac{d\pi_1^{EYm}}{dt}\Big|_{t\to t_1^{Y+}} = -\frac{4(a-c)+11\varepsilon}{15} < 0$, $\frac{d\pi_1^{EYm}}{dt}\Big|_{t\to t_2^{Y-}} = \frac{d\pi_1^{EYf}}{dt}\Big|_{t\to t_2^{Y+}} = -\frac{4[3(a-c)-2\varepsilon]}{45} < 0$, $\pi_1^{EYr}(t_1^Y) = \pi_1^{EYm}(t_1^Y) = \frac{(a-c)^2 + 18(a-c)\varepsilon + 6\varepsilon^2}{25}$, $\pi_1^{EYm}(t_2^Y) = \pi_1^{EYf}(t_2^Y) = \frac{9(a-c)^2 + 138(a-c)\varepsilon + 29\varepsilon^2}{225}$, $\frac{d^2\pi_1^{EYr}}{dt^2} = \frac{8}{9} > 0$, $\frac{d^2\pi_1^{EYm}}{dt^2} = \frac{41}{18} > 0$, and $\frac{d^2\pi_1^{EYf}}{dt^2} = \frac{8}{9} > 0$.

From (23), we can see that $\pi_1^{ED}(t)$ is continuous, convex and decreasing on t, because, $\frac{d\pi_1^{EDr}}{dt}\Big|_{t\to t_1^{D-}} = \frac{d\pi_1^{EDm}}{dt}\Big|_{t\to t_1^{D+}} = -\frac{8(a-c)+29\varepsilon}{30} < 0$, $\frac{d\pi_1^{EDm}}{dt}\Big|_{t\to t_2^{D-}} = \frac{d\pi_1^{EDf}}{dt}\Big|_{t\to t_2^{D+}} = -\frac{2(2a-2c-3\varepsilon)}{15} < 0$, $\frac{d^2\pi_1^{EDr}}{dt^2} = \frac{8}{9} > 0$, $\frac{d^2\pi_1^{EDm}}{dt^2} = \frac{41}{18} > 0$, $\frac{d^2\pi_1^{EDf}}{dt^2} = \frac{8}{9} > 0$, $\pi_1^{EDr}(t_1^D) = \pi_1^{EDm}(t_1^D) = \frac{4(a-c)^2 + 104(a-c)\varepsilon + \varepsilon^2}{100}$, $\pi_1^{EDm}(t_2^D) = \pi_1^{EDf}(t_2^D) = \frac{(a-c)^2 + 22(a-c)\varepsilon - 4\varepsilon^2}{25}$.

Proof of proposition 1