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Market Access and Technology Adoption in the Presence of FDI

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Abstract

This paper theoretically investigates whether improved access to the domestic market increases the speed with which a foreign firm adopts new technology. In our model, foreign firms choose between exporting and foreign direct investment (FDI) in serving the domestic market. In the absence of other foreign firms, a reduction in the fixed cost of FDI promotes and accelerates technology adoption by the foreign firm, while tariff-free access to the domestic market induces the most rapid timing of technology adoption. If there is another foreign firm that has already adopted the advanced technology and both firms compete in the domestic market, a reduction in the fixed cost of FDI or the elimination of the tariff may either deter or delay the timing of technology adoption. The quickest timing of technology adoption may be attained when the fixed cost of FDI and the tariff are neither very high nor very low. These results suggest that improved access to the domestic market does not necessarily contribute to the technological upgrading of foreign firms.

Keywords: Technology adoption, Tariffs, Foreign direct investment, International oligopoly
JEL classification: F12, F23, O33

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1 Introduction

The world economy has recently witnessed the increased contribution of developing countries to both global exports and outward foreign direct investment (FDI). In evidence, the exports of developing countries represented 42.8% of world exports in 2011, up from 24.2% in 1990. Similarly, the share of FDI in developing countries also increased dramatically, from 4.9% in 1990 to 22.6% in 2011.[1] For the most part, the increasing contribution of developing countries to both exports and FDI reflects the improved access of these countries to foreign markets.

Integration into the world economy has long been regarded as an important instrument for developing countries to promote economic growth. Although there are many channels through which exports and outward FDI foster economic development, one strand of research has focused on whether and how they drive the process of technological upgrading. For example, some empirical studies have investigated how trade liberalization affects technological upgrading in exporting countries. Lileeva and Trefler (2010) found that US tariff cuts induced Canadian plants to commence or increase exporting, and that these plants increased their productivity by engaging in greater product innovation and having higher adoption rates for advanced technologies. Furthermore, Bustos (2011) showed that the reduction in Brazilian tariffs associated with the formation of MERCOSUR induced Argentinean firms to adopt more advanced technology. Lastly, Aw, Roberts, and Xu (2011) showed that a reduction in trade costs increased the probability of a Taiwanese electronics plant exporting and investing in R&D.

Other empirical studies have investigated the impact of outward FDI on firm productivity. For example, Kimura and Kiyota (2006) concluded that Japanese outward FDI had a positive impact on firm productivity, while Hijzen, Inui, and Todo (2007) found that it had no significant effect on productivity if the endogeneity between outward FDI and productivity was controlled. Likewise, Bitzer and Görg (2009) investigated the productivity effect of outward FDI using data

[1] Data collected from *UNCTADstat* (http://unctadstat.unctad.org).

for 17 OECD countries and found a *negative*, although heterogeneous, relationship across countries. Finally, Barba Navaretti, Castellani, and Disdier (2010) concluded that outward FDI to developing and less developed countries led to an increase in the productivity of Italian firms but not French firms. Based on these empirical evidences, it would be safe to conclude that the productivity effect of outward FDI can be either positive or negative.

These empirical studies suggest that the productivity effect of better access to foreign markets depends on the firm's choice of mode between exporting and FDI. There have been few analyses, however, of how improved market access affects firm decisions to upgrade technology, especially given that these choices of mode are endogenously determined. Among the existing work, Saggi (1999) developed a two-period duopoly model where a firm chooses between licensing and FDI and investigated the relative impact of these modes on the incentives for R&D in the two firms. Elsewhere, Petit and Sanna-Randaccio (2000) examined how the choice between exporting and FDI affects the incentive to innovate, while Xie (2011) analyzed both theoretically and empirically how the optimal R&D investments of firms are associated with their choices between exporting, licensing, and FDI.

The purpose of this paper is to provide new insights into this area using a simple oligopoly model in which both firm location and the level of technology are endogenously determined. We then examine the effects of improved market access on technology adoption through both trade and FDI liberalization. Specifically, we develop a duopoly model where two foreign firms compete in the domestic market and each firm decides whether to serve the domestic market via exporting from the foreign country or undertaking horizontal FDI.[2] A notable feature of this analysis is that

[2]Although there are many different types of FDI possible, including vertical FDI, resource-seeking FDI, and service FDI, we focus on horizontal (or market-seeking) FDI undertaken to avoid tariffs and trade costs. In serving the market of the host country, exporting and horizontal FDI are then substitutes for firms. This choice between exporting and horizontal FDI is key to exploring the complex effect of improved market access on technology adoption.

a firm's technology choice is analyzed in a dynamic model of technology adoption. Explicitly, one of two foreign firms, which has not yet adopted an advanced technology, determines the timing of technology adoption to maximize its intertemporal profit given that the cost of technology adoption declines over time. The model also assumes away technological spillover among firms. This assumption enables us to extract the effect of improved *market access* rather than that of improved access to superior *technology*.

This setup provides some advantages over a static model of trade and FDI with endogenous R&D. First, it enables us to examine not only how firms' *ex ante* location choices affect their incentives to upgrade their technologies but also how the implemented technologies affect *ex post* the choice of location. Saggi (2009), Petit and Sanna-Randaccio (2000), and Xie (2011) considered only the ex ante effect because in their models firms choose their supply mode before they engage in R&D. The ex post effect of technology on location, however, is also important, as Helpman, Melitz, and Yeaple (2004) suggest. In our model, firms take into account how adoption changes the equilibrium location.

Second, the model can help us explore not only whether improved market access enhances technology adoption but also whether it speeds up the timing of technology adoption. If the cost of technology adoption sufficiently declines in the long run, as assumed in the basic setup, firms end up adopting new technology at some point in time, irrespective of their location choices or of government policies affecting market accessibility. Even if this is the case, the speed with which firms adopt new technology would vary if the gains from technology adoption differ. From the viewpoint of economic development, faster adoption of new technology should speed up the development process and generate higher intertemporal welfare in that country.

Finally, a dynamic model allows us to consider time-dependent policies such as temporary import protections or conditional protection, including preferential tariffs granted to developing and less developed countries. The seminal work here is Miyagiwa and Ohno (1995), who investigated the effects of permanent and temporary protection on the timing of technology adoption by the domestic firm. As in our model, Miyagiwa and Ohno (1995) also considered horizontal FDI, but their focus was on how the possible FDI of the foreign firm affects the timing of technology adoption by the domestic firm. In contrast, our focus is on how the FDI of the foreign firm affects technology adoption by the foreign firm itself.

Other theoretical studies have analyzed the timing of technology adoption in the context of international trade. For instance, Crowley (2006) compared the impacts of safeguard tariffs and antidumping duties on the outcomes of a technology adoption game between firms located in different countries. Ederington and McCalman (2008, 2009) explored how firm heterogeneity and a decline in the number of firms in an industry evolve as a result of technology adoption influenced by international trade. Using a three-country model, Mukunoki (2012) investigated how preferential trade agreements change the speed with which new technology is adopted and the speed with which multilateral free trade is realized. However, none of these studies considered the endogenous location choices of firms.

The results of the analysis are summarized as follows. If a single foreign firm serves the domestic market, liberalization of FDI, as represented by a reduction in the fixed cost of FDI, promotes technology adoption, and the timing of technology adoption is quickest if the foreign firm undertakes FDI both before and after it adopts the new technology. Trade liberalization, on the other hand, may delay the timing of technology adoption because it increases the pre-adoption profit only and decreases the gains from adoption when technology adoption changes the foreign firm's supply mode from exporting to FDI. Nonetheless, the most rapid timing of technology adoption is attained under free trade. These results suggest that in the absence of competition between foreign firms, the elimination of trade barriers contributes to the technological development of foreign countries.

In contrast, if two foreign firms compete in the domestic market, liberalization of FDI does not necessarily accelerate (and may even delay) technology adoption in the technologically lagging firm. This is because the reduction in the fixed cost of FDI promotes FDI in the technologically leading firm more, while the FDI of the rival firm in the post-adoption period intensifies product market competition and diminishes the gains from technology adoption. Conversely, the FDI of the rival firm in the pre-adoption period decreases the pre-adoption profit and may increase the gains from technology adoption if adoption blocks the rival's FDI, or if it promotes its own FDI while crowding out the rival's FDI. In the latter case, the timing of technology adoption may be quicker than where the fixed cost of FDI is removed and both firms enjoy free access to the domestic market. The same argument applies to trade liberalization, such that free trade does not necessarily maximize the speed with which the foreign firm adopts some new technology.

One policy implication drawn from these findings is that opening the home market to overseas producers and their products does not necessarily enhance technological development of those producers. To accomplish the more rapid diffusion of advanced technologies, the degree of market access should be kept neither very low nor very high in order to simultaneously increase firms' post-adoption profits and decrease their pre-adoption profits, at least temporarily. Some preferential measures, such as preferential trade and investment liberalization, may help expedite technology adoption.

The remainder of the paper is organized as follows. Section 2 develops a benchmark model where a single foreign firm chooses its supply mode and the timing of technology adoption. Section 3 details a duopoly model where two foreign firms compete in the domestic market and where both firms choose their supply mode and one decides the timing of technology adoption. Section 4 summarizes the paper and offers some concluding remarks. The Appendix contains the proofs of the lemmas and propositions.

2 The model with a single foreign firm

Let us begin with the benchmark model where only a single firm, Firm X, serves the domestic market. The inverse demand in the domestic country is given by $p = p(Q)$, where Q is the total supply of the good and $p'(Q) < 0$ holds. For simplicity, we assume that no domestic firms produce the same good. This means that Firm X acts as a monopolist in the domestic market. Changing this assumption does not change the qualitative nature of the results.

Firm X's instantaneous profit from selling the good is given by

$$\pi_X = \{p(Q) - c_X - \tau_X\} q_X, \tag{1}$$

where q_X is Firm X's sales of the good, c_X is the unit production cost of Firm X, and τ_X (≥ 0) is the specific tariff imposed on the imports of the good. Note that $\tau_X = 0$ holds if Firm X undertakes FDI and produces the good in the domestic country. Note also that $Q = q_X$ holds in the benchmark model.

The time t is a continuous variable defined on $t \in [0, +\infty)$. Sometime before $t = 0$, a new technology that reduces the variable costs of production becomes available. Firm X has not adopted the new technology by $t = 0$, and its unit cost of production with the old technology is given by $c_X = \bar{c}$. By adopting the new technology, Firm X can reduce its unit production cost from $\bar{c}$ to $\underline{c}$ $(< \bar{c})$. Firm X's decision regarding technology adoption is modeled on the framework developed in Reinganum (1981) and Fudenberg and Tirole (1985). Specifically, Firm X's adoption of the new technology at time t requires a one-time fixed cost denoted by $K(t)$. We assume that $K(0) = \overline{K}$ is sufficiently high such that Firm X never adopts the new technology at $t = 0$, because it initially lacks the specific skills to implement the new technology.[3] We also assume that $K'(t) < 0$ and $K''(t) \geq 0$ for $t < \bar{t}$. This means that the fixed cost of technology adoption declines exogenously over time, although the rate of decline of the adoption cost either

[3]Keller (2004) pointed out that a firm (or a country) needs to have a certain complementary skill to successfully adopt foreign technology.

remains constant or slows. The decline in the fixed cost occurs because either Firm X accumulates knowledge about the new technology or some complementary technologies become available. We assume, however, that there is a lower bound of the adoption cost and that $K(t) = \underline{K} \geq 0$ and $K'(t) = 0$ hold for $t \geq \bar{t}$.

In each period of time, there are three stages. In Stage 1, Firm X decides whether to adopt the new technology. In Stage 2, Firm X decides whether to undertake FDI in the domestic country to produce the good there, or to produce the good in the foreign country and export it to the domestic country. If Firm X chooses FDI, it can avoid the import tariff but must incur the fixed cost of FDI, F, at each time. In Stage 3, Firm X chooses the optimal amount of q_X.

By solving the first-order condition of Firm Z's profit maximization, $d\pi_X/dq_X = 0$, in each Stage 3, we determine the optimal amount of supply. The equilibrium instantaneous profit of Firm X is denoted by $\pi_X(c_X, \tau_X)$. We can easily confirm that $\pi_X(c_X, \tau_X)$ is decreasing in c_X and τ_X.

2.1 Choice between exporting and FDI

In each Stage 2, given $c_X \in \{\bar{c}, \underline{c}\}$, Firm X chooses between exporting and FDI. As Firm X monopolizes the market and its current choice does not affect its future profit, the maximization of instantaneous profit in each time period is consistent with the maximization of the discounted sum of the profits.

If Firm X chooses FDI, its operating profit becomes $\pi_X(c_X, 0)$ because the FDI makes τ_X ineffective. Then, the gains from FDI are given by $\Omega(c_X, \tau_X) := \pi_X(c_X, 0) - \pi_X(c_X, \tau_X)$. Firm X chooses FDI if $\Omega(c_X, \tau_X) > F$ holds and chooses exporting otherwise. Note that $\Omega(c_X)$ is increasing in τ_X and $\Omega(c_X, 0) = 0$ holds. It can be easily verified that $\Omega(\underline{c}, \tau_X) \geq \Omega(\bar{c}, \tau_X)$ holds given τ_X, meaning that the gains from undertaking FDI become higher after Firm X adopts the new technology. Firm X has two potential supply strategies: exporting from the home country, denoted by E, and undertaking FDI, denoted by I. Let $S = \{E, I\}$ denote the strategy set and $s_X(c_X) \in S$ denote Firm X's equilibrium action given its unit production cost, c_X. This means that $s_X(\overline{c})$ and $s_X(\underline{c})$ denote Firm X's location choices before and after technology adoption, respectively. For instance, $(s_X(\overline{c}), s_X(\underline{c})) = (E, I)$ represents the case where Firm X chooses exporting before technology adoption but FDI after adoption.

Figure 1 depicts the possible equilibrium choices in (τ_X, F) space. In Region 1, in which F is high and τ is low so as to satisfy $\Omega(\underline{c}, \tau_X) \leq F$, Firm X chooses exporting both before and after it adopts the new technology, meaning that $(s_X(\overline{c}), s_X(\underline{c})) = (E, E)$ holds. In Region 2, (E, I) holds because $\Omega(\overline{c}, \tau_X) \leq F < \Omega(\underline{c}, \tau_X)$ means that FDI becomes profitable only after technology adoption. In Region 3, F is sufficiently low and t is sufficiently high such that $F < \Omega(\overline{c}, \tau_X)$ holds and Firm X undertakes FDI even before its technology adoption. This means that (I, I) holds in this region.

[Figure 1 about here]

2.2 Technology adoption

In Stage 3 in each time period, Firm X adopts the new technology if it increases the discounted sum of Firm X's profits, or otherwise continues to use the old technology. Let $\overline{\pi}_X$ and $\underline{\pi}_X$ respectively denote Firm X's instantaneous profits before and after technology adoption. Furthermore, let T denote the timing of technology adoption. Because $\overline{\pi}_X$ and $\underline{\pi}_X$ are independent of t, the discounted sum of Firm X's profits, net of the cost of technology adoption, is given by

$$\Pi_X(T) = \int_0^T e^{-rt}\overline{\pi}_X dt + \int_T^\infty e^{-rt}\underline{\pi}_X dt - e^{-rT}K(T). \tag{2}$$

Firm X chooses the timing of technology adoption that maximizes $\Pi_X(T)$. By differentiating Eq. (2) with respect to T, we have $\Pi'_X(T) = -e^{-rT}[(\underline{\pi}_X - \overline{\pi}_X) - \{rK(T) - K'(T)\}]$. Given that $K(t)$ hits the lower bound, $\underline{K}$, for $T \geq \overline{t}$, Firm X never adopts the new technology if $\Pi'_X(\overline{t}) < 0$

(i.e., $\underline{\pi}_X - \overline{\pi}_X < r\underline{K}$) holds. Otherwise, the optimal timing of technology adoption, T^*, satisfies the following equation:

$$\underline{\pi}_X - \overline{\pi}_X = rK(T^*) - K'(T^*). \quad (3)$$

We can interpret the above condition as follows. Adopting the new technology in time $t = T$ raises Firm X's instantaneous profit in that period. Hence, the left-hand side represents the marginal gains from technology adoption. By postponing technology adoption until the next time period, Firm X is able to save $rK(T)$ as the interest rate and to gain from the decline in the adoption cost by $-K'(T)$. Hence, the right-hand side of Eq. (3) represents the marginal opportunity cost of adopting the new technology in the current period. This condition requires that the optimal timing of technology adoption must equate the marginal gains and the marginal cost.

Because T^*, if it exists, is uniquely determined as long as $\underline{\pi}_X$ and $\overline{\pi}_X$ are unique and independent of T, Firm X does not use the old technology for $t \in [0, T)$ and uses the new technology for $t \in [T^*, +\infty)$. Figure 2 depicts the equilibrium timing of technology adoption. The marginal opportunity cost of technology adoption, $rK(T) - K'(T)$, is downward sloping with lower bound $r\underline{K}$ because we have assumed that $K'(t) < 0$ and $K''(t) \geq 0$ hold for $t < \overline{t}$ and $K(t) = \underline{K} \geq 0$ and $K'(t) = 0$ hold for $t \geq \overline{t}$. The marginal gains from technology adoption are independent of T and thus depicted as a horizontal line. The timing of technology adoption is determined at the intersection of these two curves. It is clear that the optimal timing of technology adoption is quicker when $\underline{\pi}_X - \overline{\pi}_X$ increases.

[Figure 2 about here]

We have three different marginal gains from technology adoption, depending on Firm X's choice between exporting and FDI. If $\Omega(\underline{c}, \tau_X) \leq F$ holds (Region 1 in Figure 1), we have $\underline{\pi}_X = \pi_X(\underline{c}, \tau_X) - F$ and $\overline{\pi}_X = \pi_X(\overline{c}, \tau_X)$ and the marginal gains become

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X). \quad (4)$$

If $\Omega(\overline{c}, \tau_X) \leq F < \Omega(\underline{c}, \tau_X)$ holds, we have $\underline{\pi}_X = \pi_X(\underline{c}, 0) - F$ and $\overline{\pi}_X = \pi_X(\overline{c}, \tau_X)$ and the marginal gains are given by

$$\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X). \tag{5}$$

In this case, Firm X's technology adoption changes its supply mode from exporting to FDI.

If $F < \Omega(\overline{c})$ holds, Firm X's supply mode is always FDI, and we have $\underline{\pi}_X = \pi_X(\underline{c}, 0) - F$ and $\overline{\pi}_X = \pi_X(\overline{c}, 0) - F$. Therefore, the marginal gain of technology adoption becomes

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0). \tag{6}$$

In the next section, we examine the effect of improved access to the domestic market on the timing of technology adoption, given that technology adoption may cause a change in Firm X's supply mode.

2.3 Liberalization of trade and FDI

We have shown that both the tariff and the fixed cost of FDI affect the equilibrium location of the foreign firm. We now examine how liberalization of trade and FDI in the domestic country affect the optimal timing of technology adoption.

First, let us examine the effect of the liberalization of FDI, represented by a decline in F, given the tariff level. Let F^0 (> 0) and τ_X^0 (> 0) denote the initial level of the fixed cost of FDI and the initial level of tariff (see Point A in Figure 1). In addition, $\widetilde{F}(c_X)$ denotes the cutoff fixed cost that satisfies $\Omega(c_X, \tau_X^0) = F$. $\Omega(\underline{c}, \tau_X^0) > \Omega(\overline{c}, \tau_X^0)$ means that $\widetilde{F}(\underline{c}) > \widetilde{F}(\overline{c})$ holds. Suppose that $\widetilde{F}(\underline{c}) < F^0$ holds such that FDI is initially unprofitable both before and after technology adoption. Starting from F^0, suppose that F is gradually reduced. This reduction does not affect $\underline{\pi}_X - \overline{\pi}_X$ as long as $\widetilde{F}(\underline{c}) \leq F^0$ holds (see Eq. (4)). However, it increases $\underline{\pi}_X - \overline{\pi}_X$ once F is sufficiently reduced so that $\widetilde{F}(\overline{c}) \leq F < \widetilde{F}(\underline{c})$ holds (see Eq. (5)). If F becomes low enough to satisfy $F < \widetilde{F}(\overline{c})$, the further reduction of F does not change $\underline{\pi}_X - \overline{\pi}_X$ (see Eq. (6)). Figure 3 depicts the relationship between F and $\underline{\pi}_X - \overline{\pi}_X$, given the tariff level.

[Figure 3 about here]

Suppose the lower bound of the cost of adoption, $\underline{K}$, is sufficiently small so that Firm X always adopts a new technology in at least some points of time. We have the following proposition.

Proposition 1 *Given the tariff level, if a single foreign firm serves the domestic market, the liberalization of FDI never delays the equilibrium timing of the foreign firm's technology adoption. The quickest timing of technology adoption is realized at any F that satisfies $F \leq \Omega(\overline{c}, \tau_X)$.*

Next, we investigate the effect of trade liberalization, represented by a decline in τ_X, given the fixed cost of FDI. We reset the initial level of the fixed cost of FDI and the initial level of tariff at F^1 and τ_X^1, respectively (see Point B in Figure 1). Let $\widetilde{\tau}_X(c_X)$ denote the cutoff tariff level that satisfies $\Omega(c_X, \tau_X) = F^1$, above which Firm X chooses FDI given c_X. It is obvious that $\widetilde{\tau}_X(\overline{c}) < \widetilde{\tau}_X(\underline{c})$ holds. Suppose that $\widetilde{\tau}_X(\underline{c}) \leq \tau_X^1$ holds such that FDI is initially profitable both before and after technology adoption. Figure 4 depicts the relationship between τ_X and $\underline{\pi}_X - \overline{\pi}_X$, given the fixed cost of FDI.

[Figure 4 about here]

Given that free trade is virtually attained in $\tau_X \in (\widetilde{\tau}_X(\underline{c}), \tau_X^1]$, the gradual reduction of τ_X from τ_X^1 does not affect $\underline{\pi}_X - \overline{\pi}_X$ in this region. If the tariff is further reduced so that $\widetilde{\tau}_X(\overline{c}) < \tau_X \leq \widetilde{\tau}_X(\underline{c})$ holds, FDI becomes unprofitable before technology adoption, although it is still profitable after technology adoption. In this region, a reduction in τ_X only increases the pre-adoption instantaneous profit, $\overline{\pi}_X = \pi_X(\overline{c}, \tau_X)$, and thereby decreases the marginal gains from adoption, $\underline{\pi}_X - \overline{\pi}_X$. Once the tariff is sufficiently reduced to satisfy $\tau_X \leq \widetilde{\tau}_X(\overline{c})$, Firm X chooses exporting both before and after technology adoption. In this case, a reduction in τ_X increases both $\underline{\pi}_X$ and $\overline{\pi}_X$. We can verify that it increases $\underline{\pi}_X - \overline{\pi}_X$ because trade liberalization benefits Firm X more if it uses better technology. At $\tau_X = 0$, free trade is realized and the marginal gains from technology adoption coincide with those in the case of $\tau_X \in (\widetilde{\tau}_X(\underline{c}), \tau_X^1]$ where Firm X always chooses FDI. We have the following proposition.

Proposition 2 *Given the fixed cost of FDI, if a single foreign firm serves the domestic market, trade liberalization: (i) does not change the equilibrium timing of technology adoption if* $\widetilde{\tau}_X(\underline{c}) < \tau_X$ *holds; (ii) delays technology adoption if* $\widetilde{\tau}_X(\overline{c}) < \tau_X \leq \widetilde{\tau}_X(\underline{c})$ *holds; and (iii) accelerates technology adoption if* $\tau_X < \widetilde{\tau}_X(\overline{c})$ *holds. The quickest technology adoption is attained if either* $\widetilde{\tau}_X(\underline{c}) < \tau_X$ *or* $\tau_X = 0$ *holds.*

We have supposed that $\underline{K}$ is low. Suppose that $\underline{K}$ is sufficiently large such that Firm X never adopts the new technology with a certain parameterization of F and τ. In this case, we have the following corollary.

Corollary 1 *If the foreign firm adopts the new technology, it always does so when it is free from tariffs both before and after technology adoption.*

These results suggest that securing free access to the domestic market both before and after technology adoption promotes technology adoption in the foreign firm and induces the quickest timing of adoption, whether it is actually attained by the elimination of the tariff ($\tau_X = 0$) or virtually attained by horizontal FDI.

3 The model with two foreign firms

In this section, we analyze the alternative mode with multiple foreign firms. Suppose that another foreign firm, Firm Y, serves the domestic market along with Firm X. We assume that Firm Y has already adopted the new technology at $t = 0$, and its instantaneous profit is given by

$$\pi_X = \{p(Q) - \underline{c} - \tau_Y\} q_Y, \tag{7}$$

where q_Y is Firm Y's sales of the good and τ_Y is the specific tariff imposed on the good produced by Firm Y. The instantaneous profit of Firm X is given by (1). In this model, $Q = q_X + q_Y$ holds. For simplicity, we assume a linear demand curve, $p(Q) = a - bQ$; however, the main results are unchanged even if we consider nonlinear demand as long as we have the same strategic interactions between the two firms.

As in the benchmark model, there are three stages in each time period. In Stage 1, Firm X chooses whether to adopt the new technology In Stage 2, the two firms simultaneously decide their supply modes. In Stage 3, they engage in Cournot competition in the domestic market. We assume that the two firms follow Markov strategies in their location choices and product market competition.[4] This rules out the possibility of cooperative behaviors that might occur in repeated games.

In Stage 3, by solving the first-order conditions for profit maximization, the equilibrium instantaneous profits of Firm X and Firm Y are denoted by $\pi_X(c_X, \tau_X, \tau_Y)$ and $\pi_Y(c_X, \tau_X, \tau_Y)$, respectively. An increase in each firm's own cost of supply decreases its profit, whereas an increase in the rival's cost increases the profit. This means that $\partial\pi_X/\{\partial c_X\} < 0 < \partial\pi_Y/\{\partial c_X\}$, $\partial\pi_X/\{\partial\tau_X\} < 0 < \partial\pi_Y/\{\partial\tau_X\}$, and $\partial\pi_Y/\{\partial\tau_Y\} < 0 < \partial\pi_X/\{\partial\tau_Y\}$ hold.

3.1 Choice between exporting and FDI

In Stage 2 in each time, given $c_X \in \{\overline{c}, \underline{c}\}$, the two firms simultaneously decide whether to undertake FDI. The firm which undertakes FDI must incur the fixed cost of FDI, F, in each time. Firm X's gain from FDI is given by $\Omega_X(c_X, \tau_X, \tau_Y) := \pi_X(c_X, 0, \tau_Y) - \pi_X(c_X, \tau_X, \tau_Y)$, and Firm Y's gain is given by $\Omega_Y(c_X, \tau_X, \tau_Y) := \pi_Y(c_X, \tau_X, 0) - \pi_Y(c_X, \tau_X, \tau_Y)$.

If both firms produce in the same foreign country, it is natural to suppose that the same import tariff is applied. Even if they locate in different foreign countries, however, they still

[4]Markov strategies require that for each firm and time t, the same choice must be made if any two histories have the same state. In this model, the state variables are c_X, τ_X, and τ_Y.

face the same tariff level because the domestic country cannot use tariffs to discriminate between foreign countries because of the Most-Favored Nation principle of the GATT/WTO. This means that $\tau_i = \tau$ (≥ 0) holds if Firm i $(i \in \{X, Y\})$ chooses exporting and $\tau_i = 0$ holds if it chooses FDI.

Given that the rival foreign firm chooses exporting, Firm X's and Firm Y's gains from FDI (gross of the fixed cost of FDI) are given by

$$\Omega_X(c_X, \tau, \tau) = \pi_X(c_X, 0, \tau) - \pi_X(c_X, \tau, \tau), \tag{8}$$

$$\Omega_Y(c_X, \tau, \tau) = \pi_Y(c_X, \tau, 0) - \pi_Y(c_X, \tau, \tau), \tag{9}$$

respectively. Given that the rival firm undertakes FDI, they are given by

$$\Omega_X(c_X, \tau, 0) = \pi_X(c_X, 0, 0) - \pi_X(c_X, \tau, 0), \tag{10}$$

$$\Omega_Y(c_X, 0, \tau) = \pi_Y(c_X, 0, 0) - \pi_Y(c_X, 0, \tau). \tag{11}$$

We have the following lemma.

Lemma 1 *Given* $\tau > 0$, *(i)* $\Omega_X(\overline{c}, \tau, \tau) > \Omega_X(\overline{c}, \tau, 0)$ *and* $\Omega_Y(\overline{c}, \tau, \tau) > \Omega_Y(\overline{c}, 0, \tau)$ *hold, (ii)* $\Omega_Y(\overline{c}, \tau, \tau) > \Omega_X(\overline{c}, \tau, \tau)$ *and* $\Omega_Y(\overline{c}, 0, \tau) > \Omega_X(\overline{c}, \tau, 0)$ *hold, (iii)* $\Omega_X(\underline{c}, \tau, \tau) = \Omega_Y(\underline{c}, \tau, \tau) > \Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau)$ *holds, and (iv)* $\Omega_Y(\overline{c}, \tau, \tau) > \Omega_Y(\underline{c}, \tau, \tau)$ *and* $\Omega_X(\underline{c}, \tau, 0) > \Omega_X(\overline{c}, \tau, 0)$ *hold.*

This lemma implies that: (i) each firm's gain from undertaking FDI becomes lower if the rival firm also undertakes FDI, meaning that the two firms' FDIs are strategic substitutes; (ii) Firm Y's gain is higher than Firm X's gain before Firm X's adoption of the new technology, if evaluated at the same supply mode of the rival firm, because Firm Y produces at lower unit cost; (iii) the gains from undertaking FDI are the same in the two firms after technology adoption; and (iv) eliminating the technology gap using technology adoption diminishes Firm Y's gain from FDI and increases Firm X's gain from FDI.

Although the ranking between $\Omega_X(\overline{c}, \tau, \tau)$ and $\Omega_Y(\overline{c}, 0, \tau)$ is ambiguous, we focus only on the case where $\Omega_X(\overline{c}, \tau, \tau) < \Omega_Y(\overline{c}, 0, \tau)$ holds to rule out multiple location equilibria before technology adoption.[5]

Let $s_i(c_X) \in S = \{E, I\}$ denote Firm i's equilibrium action given Firm X's unit production cost and let $(s_X(\overline{c}), s_X(\underline{c}); s_Y(\overline{c}), s_Y(\underline{c}))$ denote the equilibrium outcome of location choices. For instance, $(E, I; I, I)$ means that Firm X chooses exporting before but FDI after technology adoption, and Firm Y chooses FDI both before and after Firm X's technology adoption.

Figure 5 depicts the possible equilibrium choices in the (τ, F) space. In Region I, $\Omega_Y(\overline{c}, \tau, \tau) \leq F$ holds and the equilibrium outcome becomes $(E, E; E, E)$. Neither Firm X nor Firm Y undertakes FDI in this case. In Region II, $\Omega_X(\underline{c}, \tau, \tau) = \Omega_Y(\underline{c}, \tau, \tau) \leq F < \Omega_Y(\overline{c}, \tau, \tau)$ holds and the equilibrium outcome becomes (E, E, I, E). Before Firm X's technology adoption, Firm Y undertakes FDI. Firm Y's FDI, however, becomes unprofitable after Firm X adopts the new technology because Firm Y no longer enjoys a technological advantage over Firm X. Firm X still does not undertake FDI in this case.

In Region III, where $\Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau) \leq F < \Omega_X(\underline{c}, \tau, \tau) = \Omega_Y(\underline{c}, \tau, \tau)$ holds, the equilibrium outcome becomes either $(E, E; I, I)$ or $(E, I; I, E)$. In this case, only Firm Y undertakes FDI before Firm X's technology adoption but either Firm X or Firm Y undertakes FDI after the technology adoption. This means that the technology adoption may cause the FDI firm to change from Firm Y to Firm X.

In Region IV, $\Omega_X(\overline{c}, \tau, 0) \leq F < \Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau)$ holds and the technology adoption induces Firm X's FDI without crowding out Firm Y's FDI made before the technology adoption. The equilibrium outcome becomes $(E, I; I, I)$. In Region V, $F < \Omega_X(\overline{c}, \tau, 0)$ holds and both firms

[5] If $\Omega_X(\overline{c}, \tau, \tau) \geq \Omega_Y(\overline{c}, 0, \tau)$ holds, there exists a case in equilibrium where one of the two firms undertakes FDI while the other chooses exporting, and so which particular firm becomes the FDI firm is undetermined (i.e., either Firm X or Firm Y can be the FDI firm under the same parameter values). With the linear-demand, the inequality holds if $\overline{c} - \underline{c} \geq \tau/3$ holds.

always engage in FDI. The equilibrium outcome becomes $(I, I; I, I)$.

[Figure 5 about here]

3.2 Technology adoption

In Stage 1, Firm X chooses the timing of technology adoption by correctly anticipating how its technology adoption affects the location decisions in Stage 2. The optimal timing is determined by Eq. (3). The marginal gains from technology adoption, $\underline{\pi}_X - \overline{\pi}_X$, now depend on both firms' choices between exporting and FDI. If $\Omega_Y(\overline{c}, \tau, \tau) \leq F$ holds (Region I in Figure 5), the marginal gains from technology adoption become

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, \tau). \tag{12}$$

If $\Omega_X(\underline{c}, \tau, \tau) = \Omega_Y(\underline{c}, \tau, \tau) \leq F < \Omega_Y(\overline{c}, \tau, \tau)$ holds (Region II in Figure 5), they become

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0). \tag{13}$$

If $\Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau) \leq F < \Omega_X(\underline{c}, \tau, \tau) = \Omega_Y(\underline{c}, \tau, \tau)$ holds (Region III in Figure 5), there are two possible equilibrium outcomes, $(E, E; I, I)$ or $(E, I; I, E)$, because either Firm X or Firm Y undertakes FDI after the technology adoption.[6] If it is anticipated that $(E, E; I, I)$ will be realized, the gains from technology adoption are given by

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0), \tag{14}$$

and if it is anticipated that $(E, I; I, E)$ will be realized, they are given by

$$\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, \tau) - F\} - \pi_X(\overline{c}, \tau, 0). \tag{15}$$

[6] The two possible equilibria mean that we may have observed repeated turnovers of the firms' locations and fluctuating marginal gains from technology adoption for $t \geq T^*$. As we assume that the two firms follow Markov strategies, however, the same equilibrium locations persist as those realized at $t = T^*$.

If $\Omega_X(\overline{c}, \tau, 0) \le F < \Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau)$ holds (Region IV in Figure 5), the equilibrium locations become $(E, I; I, I)$ and the gains from technology adoption become

$$\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, 0) - F\} - \pi_X(\overline{c}, \tau, 0). \tag{16}$$

Finally, if $F < \Omega_X(\overline{c}, \tau, 0)$ holds (Region V in Figure 5), the equilibrium locations are $(I, I; I, I)$, and the gains from technology adoption become

$$\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0). \tag{17}$$

3.3 Liberalization of trade and FDI

In this subsection, we explore the effects of the liberalization of FDI and trade liberalization in the presence of two foreign firms. To explore the effect of liberalization of FDI, let F^0 and τ^0 denote the initial level (Point A in Figure 5) and define the cutoff levels of the fixed cost, given τ^0, as $\widehat{F}(\overline{c}) = \Omega_Y(\overline{c}, \tau^0, \tau^0)$, $\widehat{F}(\underline{c}) = \Omega_X(\underline{c}, \tau^0, \tau^0) = \Omega_Y(\underline{c}, \tau^0, \tau^0)$, $\widehat{F'}(\underline{c}) = \Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, 0, \tau)$ and $\widehat{F'}(\overline{c}) = \Omega_X(\overline{c}, \tau, 0)$. We have $\widehat{F}(\overline{c}) > \widehat{F}(\underline{c}) > \widehat{F'}(\underline{c}) > \widehat{F'}(\overline{c})$.

Starting from $F = F^0$, the gradual reduction of F to $F = 0$ changes the equilibrium location choices from $(E, E; E, E)$ to $(E, E; I, E)$, $(E, E; I, E)$ to either $(E, E; I, I)$ or $(E, I; I, E)$, either $(E, E; I, I)$ or $(E, I; I, E)$ to $(E, I; I, I)$, and then $(E, I; I, I)$ to $(I, I; I, I)$. The relationship between F and Firm X's gains from technology adoption, $\underline{\pi}_X - \overline{\pi}_X$, depends on the size of the domestic market and the gap between $\overline{c}$ and $\underline{c}$. Figure 6 shows the case when the market size is large and the technology gap, $\overline{c} - \underline{c}$, is small.

[Figure 6 about here]

As long as $\widehat{F}(\overline{c}) \le F$ holds, a reduction in F does not affect $\underline{\pi}_X - \overline{\pi}_X$. Once F falls into $\widehat{F}(\underline{c}) \le F < \widehat{F}(\overline{c})$, $\underline{\pi}_X - \overline{\pi}_X$ jumps up from $\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, \tau)$ to $\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)$. The latter is larger than the former because the rival firm, Firm Y, undertakes FDI before Firm X's technology adoption in this region. The FDI only decreases Firm X's pre-adoption profits because Firm Y will switch to exporting after Firm X's technology adoption. This increases the gain from the adoption. In other words, the technology adoption not only reduces the production cost, but also blocks Firm Y's FDI. The latter effect disproportionately increases the gains from technology adoption. Within $\widehat{F}(\underline{c}) \leq F < \widehat{F}(\overline{c})$, a reduction in F has no effect because Firm X always chooses exporting.

If F is further reduced to fall into $\widehat{F}'(\underline{c}) \leq F < \widehat{F}(\underline{c})$, there are two possibilities because there are two possible location equilibria in this range. If the equilibrium outcome becomes $(E, I; I, E)$, $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, \tau) - F\} - \pi_X(\overline{c}, \tau, 0)$ holds and it is higher than that in Region II. This is because Firm X's technology adoption induces its own FDI while crowding out the rival's FDI. Note that $\underline{\pi}_X - \overline{\pi}_X$ is increasing in a reduction in F in this range, and it takes its maximum level at $F = \widehat{F}'(\underline{c})$, with which $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, \tau) - \pi_X(\underline{c}, 0, 0)\} + \{\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)\}$ holds. If the equilibrium outcome becomes $(E, E; I, I)$, on the other hand, $\underline{\pi}_X - \overline{\pi}_X$ drops down from $\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)$ in Region II to $\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)$. It is even lower than $\underline{\pi}_X - \overline{\pi}_X$ in Region I, because Firm Y always undertakes FDI and the FDI diminishes the post-adoption profit more than the pre-adoption profit of Firm X.

If F becomes low enough to satisfy $\widehat{F}'(\overline{c}) \leq F < \widehat{F}'(\underline{c})$, the equilibrium location becomes $(E, I; I, I)$. Compared with the case with $(E, E; I, I)$ in Region III, the gains from technology adoption become higher and are given by $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, 0) - F\} - \pi_X(\overline{c}, \tau, 0)$. In this range, $\underline{\pi}_X - \overline{\pi}_X$ is increasing in a reduction in F, and it takes $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0)$ at $F = \widehat{F}'(\overline{c})$. Then, a further reduction in F realizes $(I, I; I, I)$ as the equilibrium locations, and $\underline{\pi}_X - \overline{\pi}_X$ becomes the same as that realized at $F = \widehat{F}'(\overline{c})$. What is important is that the gains from technology adoption in Regions V are lower than those in Region II if the market size is large and the efficiency gap between the new and the old technologies is small..If $(E, I; I, E)$ is realized, they are also lower than those in Region III in the same situation.

When the market size is small and the technology gap, $\overline{c} - \underline{c}$, is large, the ranking of the gains from technology adoption between Region V and Region II and between Region V and Region III with $(E, I; I, E)$ are reversed. Figure 7 shows the case where the gains from technology adoption become the largest in Region V.

[Figure 7 about here]

Now let us compare the equilibrium timing of technology adoption. Suppose the lower bound of the cost of adoption, $\underline{K}$, is sufficiently small so that Firm X always adopts a new technology at some points in time. We have the following proposition.

Proposition 3 *Given the tariff level, if two foreign firms serve the domestic market and one has already adopted the new technology, liberalization of FDI may either accelerate or delay the equilibrium timing of technology adoption. If the equilibrium location is* $(E, I; I, E)$ *in* $F \in [\widehat{F}'(\underline{c}), \widehat{F}(\underline{c}))$ *and* $a > \overline{c} + 3(\overline{c} - \underline{c}) - \tau/2$ *holds, the quickest timing of technology adoption is attained at* $F = \widehat{F}'(\underline{c})$. *If the equilibrium location is* $(E, E; I, I)$ *in* $F \in [\widehat{F}'(\underline{c}), \widehat{F}(\underline{c}))$ *and* $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau/2\}$ *holds, it is attained at any* F *that satisfies* $F \in [\widehat{F}(\underline{c}), \widehat{F}(\overline{c}))$. *Otherwise, it is attained at any* F *that satisfies* $F \leq \widehat{F}'(\overline{c})$.

When two foreign firms compete in the domestic market, the relationship between the liberalization of FDI and the gains from technology adoption becomes more complicated. A reduction in F basically promotes the FDI of both firms, but promotes Firm Y's FDI more before Firm X adopts the new technology. Hence, if F is reduced to promote Firm Y's FDI in the pre-adoption period but remains high enough to block both firms' FDI in the post-adoption period (Region II), the liberalization of FDI provides Firm X with an extra incentive to adopt the new technology because the adoption changes the rival's supply mode from FDI to exporting. In addition to the crowding-out effect of Firm Y's FDI, a further reduction in F may induce Firm X's FDI in the post-adoption period and increase the gains further (Region III). At the same level of F, however, the gains become lower than the case where both firms always choose exporting if Firm Y, but not Firm X, becomes the FDI firm in the post-adoption period.

If F becomes sufficiently low to ensure Firm Y's FDI in all periods (Region IV), technology adoption no longer has a crowding-out effect and only induces Firm X's FDI in the post-adoption period. In this case, the level of F determines whether the reduction from F^0 speeds up the timing of technology adoption. If F becomes low enough to ensure both firms' FDI in all periods (Region V), the timing of technology adoption is always quicker than the timing under the initial level of the fixed cost. If the market size is large and the cost reduction by technology adoption is small, however, it is slower than the timing of adoption in the middle range of F where technology adoption has a crowding-out effect on FDI. Otherwise, the quickest timing of technology adoption is attained when both firms undertake FDI both before and after firm X's technology adoption.

We now consider the effect of trade liberalization. The initial level of the fixed cost of FDI and the initial level of tariff are set at F^1 and τ^1, respectively (see Point B in Figure 5). Initially, $\Omega_X(\overline{c}, \tau^1, 0) > F^1$ holds such that the equilibrium locations become $(I, I; I, I)$. Let $\widehat{\tau}(\overline{c})$, $\widehat{\tau}(\underline{c})$, $\widehat{\tau}'(\underline{c})$, and $\widehat{\tau}'(\overline{c})$ denote the cutoff levels of tariff that satisfy $\Omega_Y(\overline{c}, \widehat{\tau}(\overline{c}), \widehat{\tau}(\overline{c})) = F^1$, $\Omega_X(\underline{c}, \widehat{\tau}(\underline{c}), \widehat{\tau}(\underline{c})) = \Omega_X(\underline{c}, \widehat{\tau}(\underline{c}), \widehat{\tau}(\underline{c})) = F^1$, $\Omega_X(\underline{c}, \widehat{\tau}'(\underline{c}), 0) = \Omega_X(\underline{c}, 0, \widehat{\tau}'(\underline{c})) = F^1$, and $\Omega_X(\overline{c}, \widehat{\tau}'(\overline{c}), 0) = F^1$, respectively. As shown in Figure 5, $\widehat{\tau}(\overline{c}) < \widehat{\tau}(\underline{c}) < \widehat{\tau}'(\underline{c}) < \widehat{\tau}'(\overline{c}) < \tau^1$ holds.

As long as $\widehat{\tau}'(\overline{c}) < \tau < \tau^1$ holds (Region V in Figure 5), a tariff reduction has no effect on the marginal gains from technology adoption, which are given by $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0)$. Once the tariff is reduced to satisfy $\widehat{\tau}'(\underline{c}) < \tau \leq \widehat{\tau}'(\overline{c})$ (Region IV in Figure 5), Firm X comes to choose exporting before technology adoption, and the marginal gains from adoption become $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, 0) - F\} - \pi_X(\overline{c}, \tau, 0)$, which is lower than the gains in Region V. Within this region, a tariff reduction decreases $\underline{\pi}_X - \overline{\pi}_X$ because it increases Firm X's pre-adoption profit without changing its post-adoption profit.

If the tariff is reduced to satisfy $\widehat{\tau}(\underline{c}) < \tau \leq \widehat{\tau}'(\underline{c})$ (Region III in Figure 5), the equilibrium locations become either $(E, I; I, E)$ or $(E, E; I, I)$, and the gains from technology adoption are given by $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, \tau) - F\} - \pi_X(\overline{c}, \tau, 0)$ and $\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)$, respectively. As explained above, $\underline{\pi}_X - \overline{\pi}_X$ is higher than that in Region V if $(E, I; I, E)$ and $a > \overline{c} + 3(\overline{c} - \underline{c}) - \widehat{\tau}'(\underline{c})/2$ hold while it is lower if $(E, E; I, I)$ holds. Within the region, a tariff reduction decreases the gains from adoption in the former case, because it increases the pre-adoption profit while simultaneously decreasing the post-adoption profit. Conversely, in the latter case, it increases the gains from adoption because it increases the post-adoption profit as well as the pre-adoption profit, and the former effect is larger than the latter effect because the degree of profit increase given a tariff reduction is negatively correlated with the unit cost of production.

Once the tariff falls into $\widehat{\tau}(\overline{c}) < \tau \leq \widehat{\tau}(\underline{c})$ (Region II in Figure 5), Firm X always chooses exporting, and its technology adoption deters the rival firm's FDI that was profitable before the technology adoption. In this case, we have $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)$ and it is either increasing or decreasing in τ within the region because the tariff reduction benefits Firm X both before and after technology adoption. The gains from technology adoption are higher than those in Region V if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \widetilde{\tau}/2\}$ hold where $\widetilde{\tau}$ is the tariff level which maximizes $\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)$ in $\tau \in (\widehat{\tau}(\overline{c}), \widehat{\tau}(\underline{c})]$.

Finally, if τ becomes sufficiently small to satisfy $0 \leq \tau \leq \widehat{\tau}(\overline{c})$, the two firms always choose exporting and we have $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, \tau)$, which is increasing in tariff reduction. The gains from technology adoption become lower than those in Region V with $\tau > 0$, and the gains become the same if free trade is realized (i.e., $\tau = 0$). By summing the above comparisons, we have the following proposition.

Proposition 4 *Given the fixed cost of FDI, if two foreign firms serve the domestic market and one has already adopted the new technology, trade liberalization may either accelerate or delay the equilibrium timing of the other firm's technology adoption. If the equilibrium location is*

$(E, I; I, E)$ in $\tau \in (\widehat{\tau}(\underline{c}), \widehat{\tau}'(\underline{c})]$ and $a > \overline{c} + 3(\overline{c} - \underline{c}) - \widehat{\tau}'(\underline{c})/2$ holds or it is $(E, E; I, I)$ in $\tau \in (\widehat{\tau}(\underline{c}), \widehat{\tau}'(\underline{c})]$ and $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \widetilde{\tau}/2\}$ holds, where $\widetilde{\tau}$ maximizes the gains from technology adoption in $\tau \in (\widehat{\tau}(\overline{c}), \widehat{\tau}(\underline{c})]$, the quickest timing of technology adoption is attained at a certain τ in $\tau \in (\widehat{\tau}(\overline{c}), \widehat{\tau}'(\underline{c})]$. Otherwise, it is attained when $\widehat{\tau}'(\overline{c}) < \tau_X$ or $\tau_X = 0$ holds.

Here, trade liberalization either accelerates or delays technology adoption, as in the benchmark model. However, given that a crowding-out effect of technology adoption emerges in the middle range of tariffs, free trade may not induce the quickest timing of technology adoption with two foreign firms. Figure 8 shows the relationship between τ and $\underline{\pi}_X - \overline{\pi}_X$ when $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \widetilde{\tau}/2\}$ holds and $\underline{\pi}_X - \overline{\pi}_X$ is increasing in τ in Region II, given the fixed cost of FDI.

[Figure 8 about here]

Improved market access may even deter technology adoption itself. Let us examine what happens if the lower bound of $\underline{K}$ is very large. As neither $\tau = 0$ nor $F = 0$ maximize the gains from technology adoption under a certain parameterization, we have the following corollary.

Corollary 2 *If $\pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0) < rK$ holds, the foreign firm never adopts the new technology if it is free from tariffs in all periods. However, it may adopt the new technology if it faces tariffs in at least in some periods.*

4 Summary and conclusion

This paper examines the effects of trade and FDI liberalization on the speed with which a new technology is adopted by a foreign firm. A feature of the model is that the firms' supply modes (exporting or horizontal FDI) are endogenously determined, and both firms' locations in the pre- and post-adoption periods influence the foreign firm's incentive to adopt the new technology.

If a single foreign firm serves the domestic market, a reduction in the fixed cost of FDI speeds up adoption, and tariff-free access to the domestic market induces the fastest timing of technology adoption. If two foreign firms compete in the domestic market, a reduction in both the fixed cost of FDI and the import tariff may delay technology adoption. The quickest timing of technology adoption may be attained when the fixed cost of FDI and the tariff are neither very high nor very low. This finding suggests that improved market access does not necessarily contribute to the technological upgrading of firms.

Some directions remain for further research. First, even if limited market access leads to faster technology adoption through a reduction in the intertemporal efficiency loss, the benefit should be compared with the temporary distortions caused by the tariffs and the fixed cost of FDI. We could then use welfare analysis to derive the conditions under which the more rapid adoption of new technology improves welfare. Second, incorporating a licensing agreement between the firms into the model would be an interesting extension. Finally, we have not considered the case in which more than two firms decide the timing of technology adoption. It would be an interesting extension to investigate technology adoption games between multiple foreign firms.

Appendix

Proof of Proposition 1

By (4), (5), and (6), it is straightforward that a decrease in F increases $\underline{\pi}_X - \overline{\pi}_X$ for $F \in [\Omega(\overline{c}, \tau_X), \Omega(\underline{c}, \tau_X))$ and does not change it otherwise. A shift from (E, E) to (E, I) changes $\underline{\pi}_X - \overline{\pi}_X$ as $\{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X) - [\pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)] = \pi_X(\underline{c}, 0) - \pi_X(\underline{c}, \tau_X) - F = \Omega(\underline{c}, \tau_X) - F$, where $F \in [\Omega(\overline{c}, \tau_X), \Omega(\underline{c}, \tau_X))$ holds. As $\Omega(\underline{c}, \tau_X) > F$ holds, the shift increases $\underline{\pi}_X - \overline{\pi}_X$. A shift from (E, I) to (I, I) changes $\underline{\pi}_X - \overline{\pi}_X$ as $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) - [\{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X)] = -[\pi_X(\overline{c}, 0) - \pi_X(\overline{c}, \tau_X) - F] = -[\Omega(\overline{c}, \tau_X) - F]$, where $F \in [\Omega(\overline{c}, \tau_X), \Omega(\underline{c}, \tau_X))$ holds. As $\Omega(\overline{c}, \tau_X) \leq F$ holds, the shift increases $\underline{\pi}_X - \overline{\pi}_X$ if $\Omega(\overline{c}, \tau_X) < F$ holds and has no effect if $\Omega(\overline{c}, \tau_X) = F$.

Therefore, a decrease in F never delays the timing of technology adoption and the quickest timing of technology adoption is attained at any F that satisfies $F \leq \Omega(\overline{c}, \tau_X)$. ■

Proof of Proposition 2

(i) If $\widetilde{\tau}_X(\underline{c}) < \tau_X$ holds, we have $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0)$ and it does not depends on τ_X. This means that a decrease in τ_X does not change the equilibrium timing of technology adoption. (ii)If $\widetilde{\tau}_X(\overline{c}) < \tau_X \leq \widetilde{\tau}_X(\underline{c})$ holds, we have $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X)$ and a decrease in τ_X only increases the pre-adoption profit, $\pi_X(\overline{c}, \tau_X)$. This means that $\underline{\pi}_X - \overline{\pi}_X$ becomes smaller by a decreased in τ_X and it delays the timing of technology adoption. (iii) If $\tau_X < \widetilde{\tau}_X(\overline{c})$ holds, we have $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$. We can confirm that $\partial^2 \pi_X(c_X, \tau_X)/(\partial c_X \partial \tau_X) = -dq_X/dc_X > 0$ holds, meaning that $\pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$ becomes larger as τ_X is decreased.

At $\tau_X = \widetilde{\tau}_X(\underline{c})$, $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) = \{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X)$ holds by the definition of $\widetilde{\tau}_X(\underline{c})$. By the definition of $\widetilde{\tau}_X(\overline{c})$, $\{\pi_X(\underline{c}, 0) - F\} - \pi_X(\overline{c}, \tau_X) = \pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$ holds at $\tau_X = \widetilde{\tau}_X(\overline{c})$. Therefore, there are no discrete changes in $\underline{\pi}_X - \overline{\pi}_X$ by a tariff reduction. ■

Proof of Corollary 1

New technology is adopted at some point in time if $\underline{\pi}_X - \overline{\pi}_X > r\underline{K}$ holds. By Propositions 1 and 2, the gains from technology adoption are maximized if $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0)$ holds. This means that there always exists T^* such that $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) = rK(T^*) - K'(T^*)$ holds whenever $\underline{\pi}_X - \overline{\pi}_X > r\underline{K}$ holds at some point in time ■

Proof of Lemma 1

Given $\tau > 0$, we have (i) $\Omega_X(\overline{c}, \tau, \tau) - \Omega_X(\overline{c}, \tau, 0) = \Omega_Y(\overline{c}, \tau, \tau) - \Omega_Y(\overline{c}, 0, \tau) = 4\tau^2/9b > 0$, (ii) $\Omega_Y(\overline{c}, \tau, \tau) - \Omega_X(\overline{c}, \tau, \tau) = \Omega_Y(\overline{c}, 0, \tau) - \Omega_X(\overline{c}, \tau, 0) = 4\tau(\overline{c} - \underline{c})/3b > 0$, (iii) $\Omega_X(\underline{c}, \tau, \tau) - \Omega_X(\underline{c}, \tau, 0) = \Omega_Y(\underline{c}, \tau, \tau) - \Omega_Y(\underline{c}, 0, \tau) = 4\tau^2/9b > 0$, and (iv) $\Omega_Y(\overline{c}, \tau, \tau) - \Omega_Y(\underline{c}, \tau, \tau) = 4\tau(\overline{c} - \underline{c})/9b > 0$ and $\Omega_X(\underline{c}, \tau, 0) - \Omega_X(\overline{c}, \tau, 0) = 8\tau(\overline{c} - \underline{c})/9b > 0$. ■

Proof of Proposition 3

Starting from $F > \Omega_Y(\overline{c}, \tau, \tau)$, a gradual reduction of F changes the equilibrium locations from $(E, E; E, E)$ to $(E, E; I, E)$, $(E, E; I, E)$ to $(E, I; I, E)$ or $(E, E; I, I)$, $(E, I; I, E)$ or $(E, E; I, I)$ to $(E, I; I, I)$, and then $(E, I; I, I)$ to $(I, I; I, I)$. By (12) and (13), the shift in the equilibrium locations from $(E, E; E, E)$ in Region I to $(E, E; I, E)$ in Region II increases the gains from technology adoption as $\{\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)\} - \{\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, \tau)\} = \pi_X(\overline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0) > 0$. Suppose the equilibrium location in Region III becomes $(E, I; I, E)$. The shifts from $(E, E; I, E)$ in Region II to $(E, I; I, E)$ increases the gains from technology adoption because we have $[\{\pi_X(\underline{c}, 0, \tau) - F\} - \pi_X(\overline{c}, \tau, 0)] - \{\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)\} = \Omega_X(\underline{c}, \tau, \tau) - F = \widehat{F}(\underline{c}) - F > 0$ in $\widehat{F}'(\underline{c}) \leq F < \widehat{F}(\underline{c})$ by (13) and (15). The gains from technology adoption take the maximum level within Region III at $F = \widehat{F}'(\underline{c})$ and it is given by $\underline{\pi}_X - \overline{\pi}_X = \{\pi_X(\underline{c}, 0, \tau) - \pi_X(\underline{c}, 0, 0)\} + \{\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)\}$.

Suppose the equilibrium location in Region III becomes $(E, E; I, I)$. By (12) and (14), we have $\{\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)\} - \{\pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, \tau)\} = -[\{\pi_X(\underline{c}, \tau, \tau) - \pi_X(\underline{c}, \tau, 0)\} - \{\pi_X(\overline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)\}] < 0$ because we can confirm that $\partial \pi_X(c_X, \tau_X, \tau_Y)/\partial \tau_Y > 0$ and $\partial^2 \pi_X(c_X, \tau_X, \tau_Y)/\partial c_X \partial \tau_Y < 0$ hold. This means that the shift in the equilibrium locations from $(E, E; E, E)$ in Region I to $(E, E; I, I)$ in Region III reduces the gains from technology adoption. By (14) and (16), the shift from $(E, E; I, I)$ in Region III to $(E, I; I, I)$ in Region IV increases the gains from technology adoption because $[\{\pi_X(\underline{c}, 0, 0) - F\} - \pi_X(\overline{c}, \tau, 0)] - \{\pi_X(\underline{c}, \tau, 0) - \pi_X(\overline{c}, \tau, 0)\} = \{\pi_X(\underline{c}, 0, 0) - \pi_X(\underline{c}, \tau, 0)\} - F = \Omega_X(\underline{c}, \tau, 0) - F = \widehat{F}'(\underline{c}) - F > 0$ in $\widehat{F}'(\overline{c}) \leq F < \widehat{F}'(\underline{c})$.

By (16) and (17), the shift from $(E, I; I, I)$ in Region IV to $(I, I; I, I)$ in Region V increases the gains from technology adoption as $\{\pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0)\} - [\{\pi_X(\underline{c}, 0, 0) - F\} - \pi_X(\overline{c}, \tau, 0)] = F - \{\pi_X(\overline{c}, 0, 0) - \pi_X(\overline{c}, \tau, 0)\} = F - \Omega_X(\underline{c}, \tau, 0) = F - \widehat{F}'(\overline{c}) > 0$ holds in $0 \leq F < \widehat{F}'(\overline{c})$. The gains from technology adoption in Region V are given by $\underline{\pi}_X - \overline{\pi}_X = \pi_X(\underline{c}, 0, 0) - \pi_X(\overline{c}, 0, 0)$. By comparing the gains with those in Region II, we have $\{\pi_X(\underline{c},0,0)-\pi_X(\overline{c},0,0)\}-\{\pi_X(\underline{c},\tau,\tau)-\pi_X(\overline{c},\tau,0)\} = -\{\pi_X(\overline{c},0,0)-\pi_X(\overline{c},\tau,0)\}+\{\pi_X(\underline{c},0,0)-\pi_X(\underline{c},\tau,\tau)\}$. The first term of this equation is negative while the second term is positive, and the overall change is either positive or negative. With the linear-demand, it is positive if the market size, a, is sufficiently small to satisfy $a < \overline{c}+3\{(\overline{c}-\underline{c})+\tau/2\}$ and it is negative if the inequality is reversed. By comparing the gains from technology adoption in Region V with those in Region III with $(E,I;I,E)$, we have $\{\pi_X(\underline{c},0,0)-\pi_X(\overline{c},0,0)\}-[\{\pi_X(\underline{c},0,\tau)-\pi_X(\underline{c},0,0)\}+\{\pi_X(\underline{c},\tau,0)-\pi_X(\overline{c},\tau,0)\}] = [\{\pi_X(\underline{c},0,0)-\pi_X(\underline{c},\tau,0)\}-\{\pi_X(\overline{c},0,0)-\pi_X(\overline{c},\tau,0)\}]-\{\pi_X(\underline{c},0,\tau)-\pi_X(\underline{c},0,0)\}$. The first-term is positive while the second-term is negative, and the overall effect is either positive or negative. With the linear-demand, it is positive if $a < \overline{c}+3(\overline{c}-\underline{c})-\tau/2$ holds and negative if the inequality is reversed. By summing the above comparisons, we have Proposition 3. ■

Proof of Proposition 4

As long as $\tau > 0$ holds, the comparisons of the gains from technology adoption in Proposition 3 are valid. Starting from $\tau > \widehat{\tau}'(\overline{c})$, a gradual reduction of τ changes the equilibrium locations from $(I,I;I,I)$ to $(E,I;I,I)$, $(E,I;I,I)$ to $(E,I;I,E)$ or $(E,E;I,I)$, $(E,I;I,E)$ or $(E,E;I,I)$ to $(E,E;I,E)$, and then $(E,E;I,E)$ to $(E,E;E,E)$. These shifts either increase or decrease the gains from technology adoption. If $(E,I;I,E)$ is realized in $\widehat{\tau}(\underline{c}) < \tau \leq \widehat{\tau}'(\underline{c})$ (Region III), the gains from technology adoption is becomes $\{\pi_X(\underline{c},0,\tau)-F\}-\pi_X(\overline{c},\tau,0)$ and it is increasing in τ because $\partial\pi_X(\underline{c},0,\tau)/\partial\tau > 0$ and $\partial\pi_X(\overline{c},\tau,0)/\partial\tau < 0$ hold. By Proposition 3, This means that the maximum level of the gains from technology adoption is attained at $\tau = \widehat{\tau}'(\underline{c})$, and it is higher than those in Region V as well as those in other regions if $a > \overline{c}+3\{(\overline{c}-\underline{c})+\tau/2\}$ holds.

In Region II, the gains from technology adoption is becomes $\pi_X(\underline{c},\tau,\tau)-\pi_X(\overline{c},\tau,0)$ and $\partial\{\pi_X(\underline{c},\tau,\tau)-\pi_X(\overline{c},\tau,0)\}/\partial\tau$ can be either positive or negative. We can confirm that $\pi_X(\underline{c},\tau,\tau)-\pi_X(\overline{c},\tau,0)$ has an inverse-U shaped relation with an increase in τ. Therefore, the maximum level of the gains from technology adoption is attained at $\tau = \tau^* \equiv (a - \overline{c})/3 - (\overline{c} - \underline{c})$ if $\tau^* \in (\widehat{\tau}(\overline{c}), \widehat{\tau}(\underline{c}))$ holds, and otherwise it is attained either at $\tau \approx \widehat{\tau}(\overline{c})$ or at $\tau = \widehat{\tau}(\underline{c})$. By Proposition 3, it is higher than that in Region V if $a > \overline{c} + 3(\overline{c} - \underline{c}) - \widetilde{\tau}/2$, where $\widetilde{\tau} = \arg\max_{\tau} \pi_X(\underline{c}, \tau, \tau) - \pi_X(\overline{c}, \tau, 0)$ for $\tau \in (\widehat{\tau}(\overline{c}), \widehat{\tau}(\underline{c}))$.

If neither $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau/2\}$ nor $a > \overline{c} + 3(\overline{c} - \underline{c}) - \widetilde{\tau}/2$ holds, the gains from technology adoption are the largest in Region V or when the tariff is eliminated both before and after the technology adoption. ■

Proof of Corollary 2

New technology is never adopted when $\widehat{\tau}'(\overline{c}) < \tau_X$ or $\tau_X = 0$ if $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) < r\underline{K}$ holds. By Propositions 3 and 4, the gains from technology adoption may be higher than $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0)$ at a certain τ in $\tau \in (\widehat{\tau}(\overline{c}), \widehat{\tau}'(\underline{c})]$ if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau/2\}$ or $a > \overline{c} + 3(\overline{c} - \underline{c}) - \widetilde{\tau}/2$ holds. This means that there may exist T^* such that $\underline{\pi}_X - \overline{\pi}_X = rK(T^*) - K'(T^*)$ holds even if $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) < r\underline{K}$ holds ■

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Figures

Figure 1: The Choice between Exporting and FDI (A Single Foreign Firm)

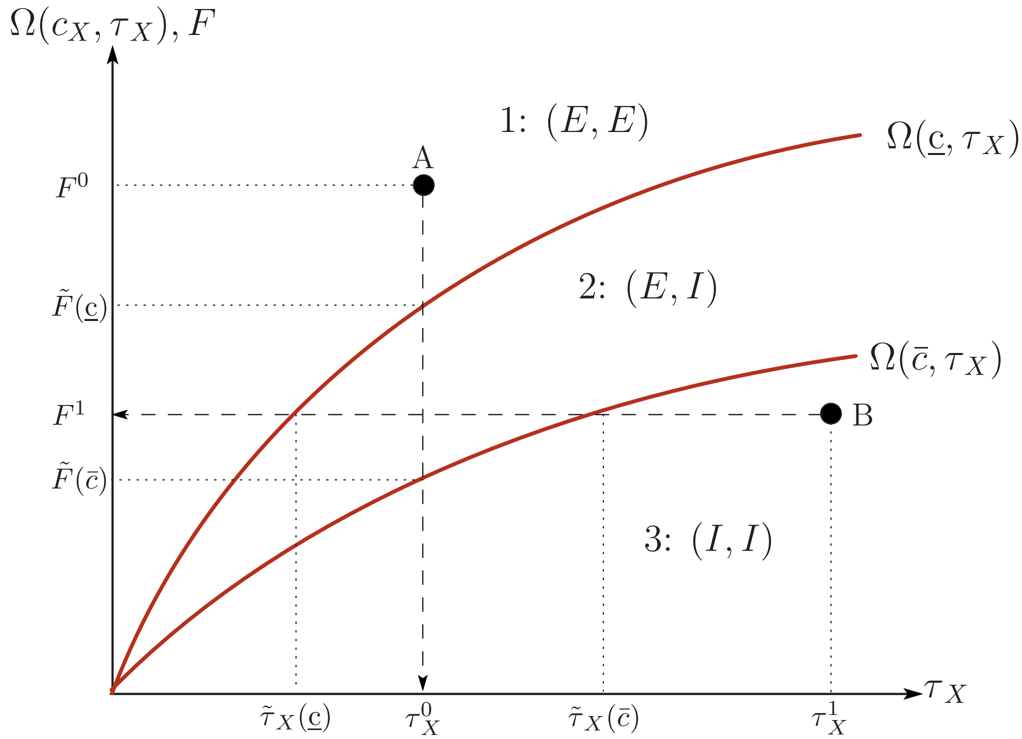

Figure 2: The Optimal Timing of Technology Adoption

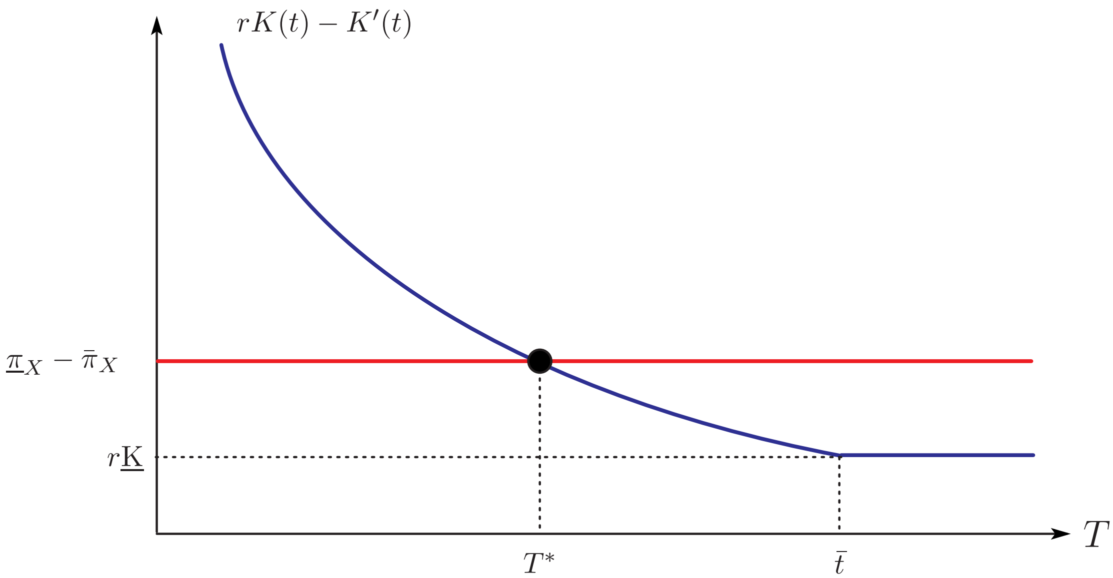

Figure 3: Liberalization of FDI (A Single Foreign Firm)

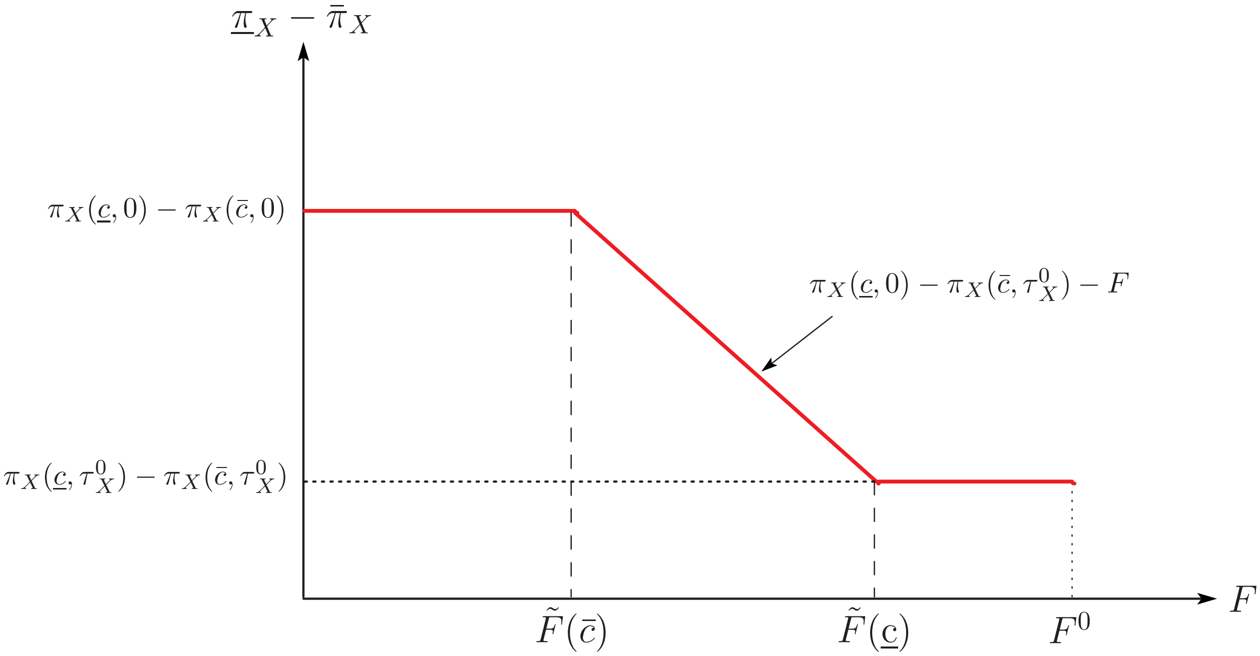

Figure 4: Trade Liberalization (A Single Foreign Firm)

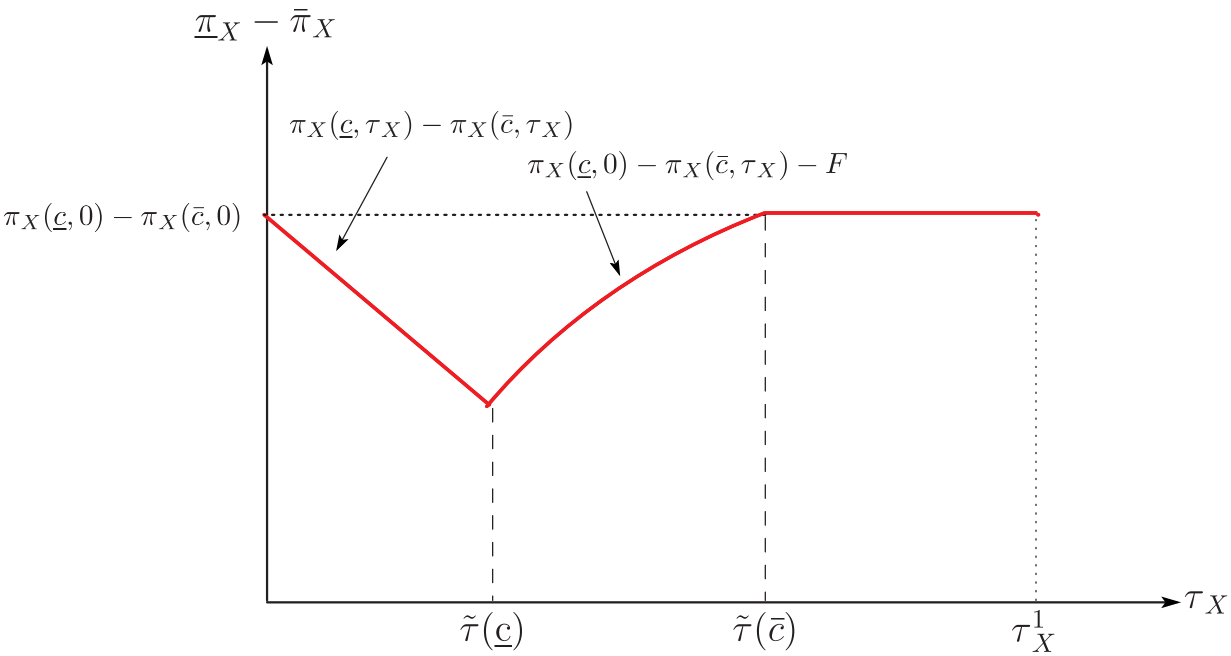

Figure 5: The Choices between Exporting and FDI (Two Foreign Firms)

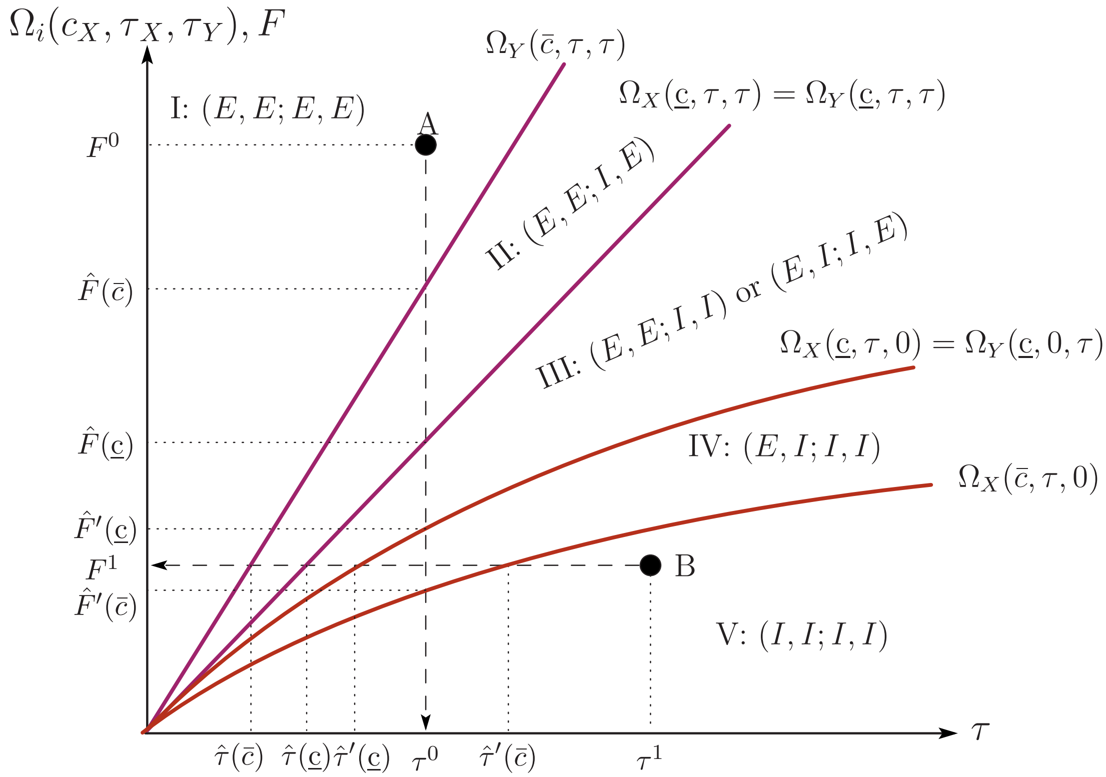

Figure 6: Liberalization of FDI with large market size and small technology gap (Two Foreign Firms)

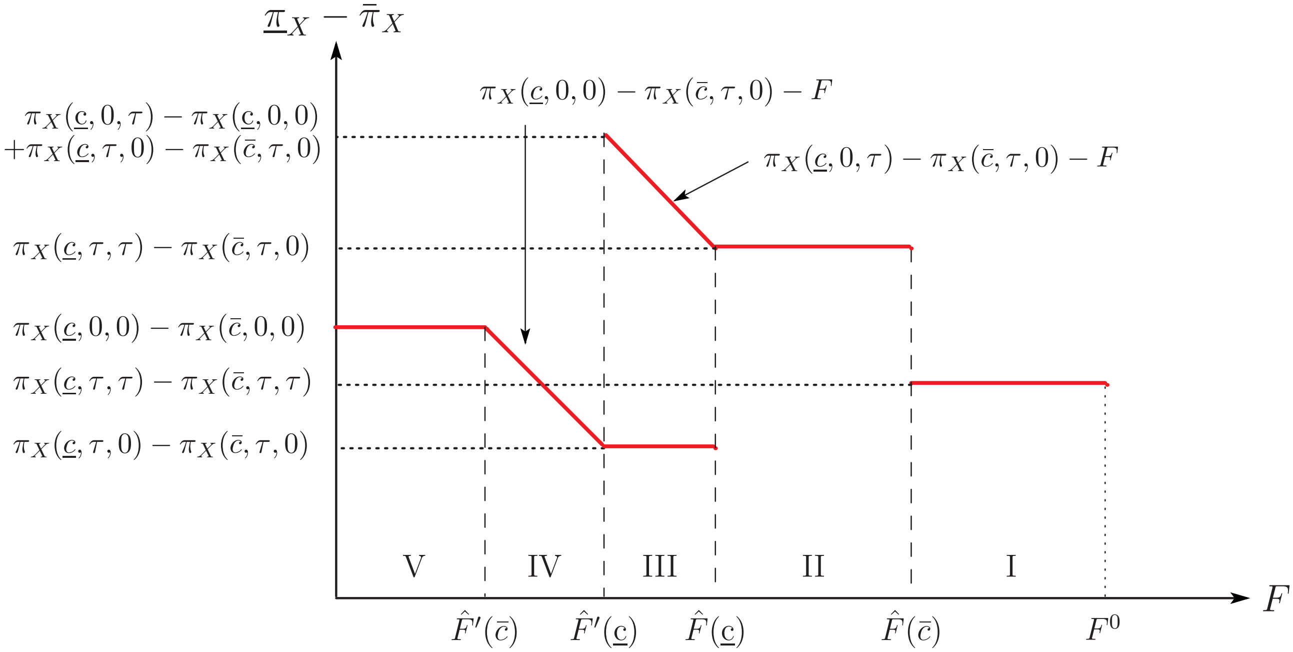

Figure 7: Liberalization of FDI with small market size and large technology gap (Two Foreign Firms)

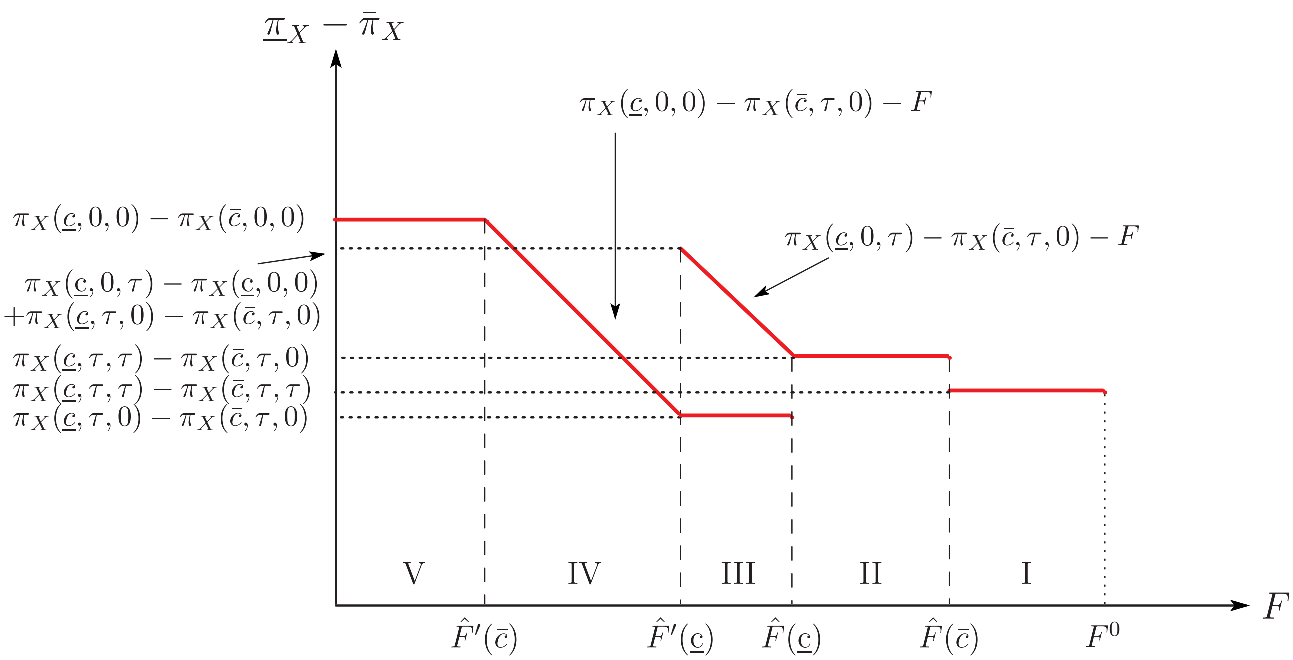

Figure 8: Trade Liberalization with large market size and small technology gap (Two Foreign Firms)