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 speeds up new technology adoption by a foreign firm adopts new technology. In our model, foreign firms choose between exporting and foreign direct investment (FDI) to serve 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 technology adoption most rapidly and realizes maximum consumer welfare. If two firms compete in the domestic market and choose the time for technology adoptions, a reduction in the fixed cost of FDI or the elimination of the trade cost may deter or delay technology adoption. Technology adoption can be quickest and consumer welfare greatest when the fixed cost of FDI and the tariff are neither very high nor very low. Preferential liberalization of FDI promotes the technology adoption of the targeted firm but it may not help consumers because it discourages technology adoption of the non-targeted firm. These results suggest that improved access to the domestic market does not necessarily contribute to the technological upgrading of foreign firms.

Key words: technology adoption, foreign direct investment, trade liberalization, international oligopoly

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1 Introduction

The world economy has witnessed an increasing contribution by developing countries to both global exports and outward foreign direct investment (FDI). That is evidenced by the fact that the merchandise exports of developing countries represented 44.8% of world exports in 2015, up from 24.2% in 1990. Similarly, the developing countries' share of outward FDI also increased dramatically, from 5.4% in 1990 to 25.6% in 2015.[1] For the most part, the increasing contribution by developing countries to both exports and outward 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. Bustos (2011) showed that the reduction in Brazilian tariffs associated with the formation of Mercado Común del Sur (MERCOSUR) induced Argentinean firms to adopt more advanced technology. Aw, Roberts, and Xu (2011) showed that a reduction in trade costs increased the probability of exports and R&D investments by a Taiwanese electronics plant.

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 no significant effect on productivity if the endogeneity between outward FDI and productivity was controlled for. Likewise, Bitzer and Görg (2009) investigated the productivity effect of outward FDI using data for 17 OECD countries and found a *negative*, although heterogeneous, relationship across countries. Chen and Yang (2013) found that a relationship between a firm's outward FDI and domestic R&D is indeterminate. Lancheros (2016) found that, although exporting has encouraged domestic firms to upgrade their technology, outward FDI has acted as a substitute for such technological activities. 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

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

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. 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 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 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 undertake horizontal FDI.[2] A notable feature of this analysis is that a firm's technology choice is analyzed in a dynamic model of technology adoption (TA). Explicitly, two foreign firms, which have not yet adopted advanced technology, determine the timing of TA to maximize its intertemporal profit given that the cost of TA 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 TA but also whether it speeds up TA. If the cost of TA 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 government policies affecting market access. Even so, the speed of new TA by firms would vary if the gains from TA 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.

The seminal work here is that of Miyagiwa and Ohno (1995), who investigated the effects of permanent

[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 TA.

and temporary protection on the timing of TA for 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 TA for the domestic firm. In contrast, our focus is on how the FDI of the foreign firm affects TA by the foreign firm itself.

Other theoretical studies have analyzed the timing of TA 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 TA influenced by international trade. Vashchilko (2013) showed that a decrease in the tariff on the imports of final products and an increase in the tariff on the imports of inputs speed up TA by the domestic firm. Using a three-country model, Mukunoki (2015) investigated how preferential trade agreements change the speed of both new technology adoption and realization of multilateral free trade. 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, represented by a reduction in the fixed cost of FDI, promotes TA, TA is quickest if the foreign firm undertakes FDI both before and after new technology adoption. Trade liberalization, on the other hand, may delay the timing of TA because it increases only the pre-adoption profit and decreases the gains from TA when the foreign firm's supply mode changes from exporting to FDI as a result of TA. Nonetheless, TA is attained most rapidly under free trade. These results suggest that in the absence of competition between foreign firms, elimination of trade barriers contributes to the technological development of foreign countries. Since improved access to the domestic market promotes TA and FDI at the same time, free trade or free FDI to the domestic market maximizes the domestic consumer surplus. However, these results contradict the aforementioned empirical results that improved access to international markets may not encourage or it can even discourage technological advancements in developing countries.

In contrast, if two foreign firms compete in the domestic market, multilateral liberalization of FDI does not necessarily accelerate (but may even delay) TA in the technologically lagging firm. This is because reduction in the fixed cost of FDI leads to greater promotion of FDI in the technologically leading firm, while the FDI of the rival firm in the post-adoption period intensifies product market competition and diminishes the gains from TA. Conversely, the FDI of the rival firm in the pre-adoption period decreases the pre-adoption profit and may increase the gains from TA if adoption blocks the rival's FDI (FDI blocking effect), or if it promotes its own FDI while crowding out the rival's FDI (FDI conversion effect). In the latter case, TA may be quicker and consumer surplus larger compared to a situation where the fixed cost of FDI is removed and both firms enjoy free access to the domestic market. These intertemporal changes in FDI patterns is consistent with the fact that the firms' foreign affiliates frequently enter and exit the market in the real world.[3] The same argument applies to multilateral trade liberalization, so that free trade does not necessarily maximize the speed of new technology adoption by foreign firms. These results indicate that strategic interactions among firms in both TA and FDI are keys to explain the reason why the relationship between improving market access and technology upgradings is not monotone in the existing empirical analyses.

The paper also investigates whether preferential liberalization of FDI targeted at one of the two firms may help expedite TA. For instance, many countries have concluded bilateral investment treaties (BITs) with other countries and preferentially liberalize FDI measures. As of November 2016, the number of BITs in force was as much as 2324.[4] We found that preferential liberalization has a technology creation effect that promotes TA on the targeted firm (by promoting TA) and a technology diversion effect on the other firm (by discouraging TA). However, the FDI conversion effect of TA does not emerge with preferential liberalization. Therefore, consumers in the domestic country prefer preferential liberalization only if the targeted firm realizes TA much earlier than it would under multilateral liberalization.

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. For 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.

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 time 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 decide the time of technology adoption. We also compare multilateral liberalization and preferential liberalization of FDI. Section 4 conducts a welfare analysis and investigates whether liberalization benefits consumers in the domestic country. Section 5 summarizes the paper and offers some concluding remarks. The appendices provide proofs for the lemmas and propositions.

2 Improving market access with a single foreign firm

Let us begin with the benchmark model where 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

[3] Ito (2015) found that, on average, 868 foreign entities have closed their operations per year from 1997 to 2011, while there were 663 entrants per year from 1998 to 2012.

[4] Data were collected from the UNCTAD website (http://investmentpolicyhub.unctad.org/IIA).

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 affect 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 trade cost. 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 $c_X = \overline{c}$. By adopting the new technology, Firm X can reduce its unit production cost from $\overline{c}$ to $\underline{c}$ ($< \overline{c}$). Firm X's decision regarding TA is modeled according to the framework developed by Reinganum (1981) and Fudenberg and Tirole (1985). Specifically, new technology adoption by firm X 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.[5] We also assume that $K'(t) < 0$ and $K''(t) \geq 0$ for $t < \bar{t}$. This means that the fixed cost of TA declines exogenously over time, although the rate of decline of the adoption cost either remains constant or slows. The fixed cost decreases because Firm X either accumulates knowledge about the new technology or acquires some complementary technology. We assume, however, that the adoption cost has a lower bound and that $K(t) = \underline{K} \geq 0$ and $K'(t) = 0$ hold for $t \geq \bar{t}$.

At $t = 0$, each firm is pre-committed to its adoption date.[6] Each period has two stages. In Stage 1, Firm X decides whether to undertake FDI in the domestic country and produce the good there, or produce the good in the foreign country and export it to the domestic country. If Firm X chooses FDI, it can avoid the trade cost but must incur the fixed cost of FDI, F_X, at each time. In Stage 2, Firm X chooses the optimal amount of q_X.

By solving the first-order condition of Firm X's profit maximization, $d\pi_X/dq_X = 0$, in each Stage 2, 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.

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

[6] Since adopting the new technology incurs only a one-time fixed cost, Firm X has no incentives to use the old technology once it adopts the new technology.

2.1 Choice between exporting and FDI

In each Stage 1 of each period, given $c_X \in \{\overline{c}, \underline{c}\}$, 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 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 before and after its TA are respectively given by $\overline{\Omega}_X := \pi_X(\overline{c}, 0) - \pi_X(\overline{c}, \tau_X)$ and $\underline{\Omega}_X := \pi_X(\underline{c}, 0) - \pi_X(\underline{c}, \tau_X)$. Firm X undertakes FDI if $\overline{\Omega}_X > F$ holds before its TA and if $\underline{\Omega}_X > F$ holds after its TA. Note that both $\overline{\Omega}_X$ and $\underline{\Omega}_X$ are increasing in τ_X and $\overline{\Omega}_X = \underline{\Omega}_X = 0$ at $\tau_X = 0$. It can be easily verified that $\underline{\Omega}_X > \overline{\Omega}_X$ holds given $\tau_X > 0$, meaning that the gains from undertaking FDI increase 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 $s_X \in \{E, I\}$ denote Firm X's location choice action, and $\widetilde{s}_X(c_X)$ its equilibrium action given its unit production cost, c_X. This means that $\widetilde{s}_X(\overline{c})$ and $\widetilde{s}_X(\underline{c})$ denote Firm X's location choices before and after TA, respectively.

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

[Figure 1 about here]

2.2 Technology adoption

At $t = 0$, firm X chooses and commits itself to the time of its TA such that it maximizes the discounted sum of Firm X's profits. Let $\overline{\pi}_X$ and $\underline{\pi}_X$ respectively denote Firm X's instantaneous profits before and after TA. Furthermore, let T denote the time of TA. 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 TA, 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 time of TA so as to maximize $\Pi_X(T)$. Differentiating (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, $\widetilde{T}$, satisfies the following equation:

$$\Delta\pi_X := \underline{\pi}_X - \overline{\pi}_X = rK(\widetilde{T}) - K'(\widetilde{T}). \tag{3}$$

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 TA. By postponing TA 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 (3) represents the marginal opportunity cost of adopting the new technology in the current period. This condition requires that optimal timing of TA must equate the marginal gains and the marginal cost.

Because $\widetilde{T}$, 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 $t \in [0, \widetilde{T})$ and uses the new technology for $t \in [\widetilde{T}, +\infty)$. Figure 2 depicts the equilibrium timing of TA. The marginal opportunity cost of TA, $rK(T) - K'(T)$, is downward sloping with lower bound $r\underline{K}$ because we have assumed that $K'(t) < 0$ and $K''(t) \geq 0$ hold for $t < \bar{t}$ and $K(t) = \underline{K} \geq 0$ and $K'(t) = 0$ hold for $t \geq \bar{t}$. The marginal gains from TA are independent of T and thus depicted as a horizontal line. The time of TA is determined at the intersection of these two curves. It is clear that the larger $\Delta\pi_X$ is, the earlier the optimal time of TA occurs.

[Figure 2 about here]

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

$$\Delta\pi_X = \pi_X(\underline{c}, \tau_X) - \pi_X(\bar{c}, \tau_X). \tag{4}$$

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

$$\Delta\pi_X = \{\pi_X(\underline{c}, 0) - F_X\} - \pi_X(\bar{c}, \tau_X). \tag{5}$$

In this case, Firm X's TA causes its supply mode to change from exporting to FDI.

If $F_X < \overline{\Omega}_X$ holds, Firm X's supply mode does not depend on its TA and it is always FDI. We have $\underline{\pi}_X = \pi_X(\underline{c}, 0) - F_X$ and $\overline{\pi}_X = \pi_X(\bar{c}, 0) - F_X$. Therefore, the marginal gains of TA becomes

$$\Delta\pi_X = \pi_X(\underline{c}, 0) - \pi_X(\bar{c}, 0). \tag{6}$$

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

2.3 Liberalization of FDI

We have shown that both the trade cost 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 TA.

First, let us examine the effect of FDI liberalization, represented by a decline in F_X, given the level of trade cost. Let F_X^0 (> 0) and τ_X^0 (> 0) respectively denote the initial fixed cost of FDI and the initial trade cost (see Point A in Figure 1). In addition, $\underline{F}_X$ and $\overline{F}_X$ denote the cutoff fixed cost that satisfies $\underline{\Omega}_X = F_X$ and $\overline{\Omega}_X = F_X$, respectively. $\underline{\Omega}_X > \overline{\Omega}_X$ means that $\underline{F}_X > \overline{F}_X$ holds. Suppose that $\underline{F}_X < F^0$ holds such that FDI is initially unprofitable both before and after TA. Starting from F_X^0, let us consider the effect of the reduction in F_X. The reduction does not affect $\Delta\pi_X$ as long as $\underline{F}_X \leq F_X$ holds (see (4)). However, it increases $\Delta\pi_X$ once F_X reduces sufficiently for $\overline{F}_X \leq F_X <\underline{F}_X$ to hold (see (5)). Any further reduction in F_X, once it decreases sufficiently, to satisfy $F_X < \overline{F}_X$, does not change $\Delta\pi_X$ (see (6)). Figure 3 depicts the relationship between F_X and $\Delta\pi_X$, given the level of trade costs.

[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 at some point of time. We have the following proposition.

Proposition 1 *Given the level of trade cost, if a single foreign firm serves the domestic market, liberalization of FDI never delays the equilibrium time of technology adoption by the foreign firm. Technology adoption is realized at the earliest time at any F_X that satisfies $F_X \leq \overline{\Omega}_X$.*

2.4 Trade liberalization

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 fixed cost of FDI and the initial trade cost at F_X^1 and τ_X^1, respectively (see Point B in Figure 1). Let $\overline{\tau}_X$ and $\underline{\tau}_X$ denote the cutoff levels of trade cost that satisfy $\overline{\Omega}_X = F_X^1$ and $\underline{\Omega}_X = F_X^1$, respectively. It is obvious that $\underline{\tau}_X < \overline{\tau}_X$ holds. Suppose that $\overline{\tau}_X \leq \tau_X^1$ holds such that FDI is initially profitable both before and after TA. Figure 4 depicts the relationship between τ_X and $\Delta\pi_X$, given the fixed cost of FDI.

[Figure 4 about here]

Given that free trade is virtually attained in $\tau_X \in (\overline{\tau}_X, \tau_X^1]$, the gradual reduction of τ_X from τ_X^1 does not affect $\Delta\pi_X$ in this region. If the trade cost is further reduced so that $\underline{\tau}_X < \tau_X \leq \overline{\tau}_X$ holds, FDI becomes unprofitable before technology adoption, although it is still profitable after TA. In this region, a reduction in τ_X only increases the pre-adoption instantaneous profit, $\overline{\pi}_X = \pi_X(\bar{c}, \tau_X)$, and thereby decreases the marginal gains from adoption, $\Delta\pi_X$. Once the trade cost is sufficiently reduced to satisfy $\tau_X \leq \underline{\tau}_X$, Firm X chooses exporting both before and after TA. In this case, a reduction in τ_X increases both $\underline{\pi}_X$ and $\overline{\pi}_X$. We can verify that it increases $\Delta\pi_X$ 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 TA coincide with those at $\tau_X \in (\overline{\tau}_X, \tau_X^1]$, 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 time of technology adoption if $\overline{\tau}_X < \tau_X$ holds; (ii) delays technology adoption if $\underline{\tau}_X < \tau_X \leq \overline{\tau}_X$ holds; and (iii) accelerates technology adoption if $\tau_X < \underline{\tau}_X$ holds. Technology adoption is realized most rapidly if either $\overline{\tau}_X < \tau_X$ 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_X. In this case, we have the following corollary.

Corollary 1 *If $\pi_X(\underline{c}, \tau_X) - \pi_X(\bar{c}, \tau_X) < r\underline{K}$ holds for some τ_X, the foreign firm may never adopt the new technology. If the foreign firm adopts the new technology at some point in time, it always does so when it is free from trade costs both before and after technology adoption.*

These results suggest that securing free access to the domestic market both before and after TA increases the foreign firm's gains from TA and induces the quickest timing of adoption, whether it is actually attained by the elimination of the trade cost ($\tau_X = 0$) or virtually attained by horizontal FDI.

3 Improving market access with two foreign firms

We have seen that improving market access to the domestic market always accelerates TA under foreign monopoly. However, this result does not necessarily hold with multiple foreign firms. In this section, we analyze TA in the alternative model with multiple foreign firms.

3.1 The model and the equilibrium

Suppose that another foreign firm, Firm Y, serves the domestic market along with Firm X. We assume that both firms have not adopted the new technology at $t = 0$ and Firm h's ($h \in \{X, Y\}$) instantaneous profit is given by

$$\pi_h = \{p(Q) - c_h - \tau_h\}q_h, \tag{7}$$

where q_h is Firm h's sales of the good, $Q = q_X + q_Y$ is the total sales of the good, and τ_h is the specific trade cost imposed on the good produced by Firm h. For simplicity, we assume a linear demand curve, $p(Q) = a - bQ$; however, the main results remain 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 two stages in each time period, t. At $t = 0$, firms simultaneously choose the time for adoption of the new technology. In Stage 1 of each period, the two firms simultaneously decide their supply modes. In Stage 2, 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.[7] This rules out the possibility of cooperative behaviors that might occur in repeated games.

In Stage 2, by solving the first-order conditions for profit maximization, the equilibrium instantaneous profits of Firm X and Firm Y are denoted by $\pi_X(c_X, \tau_X; c_Y, \tau_Y)$ and $\pi_Y(c_Y, \tau_Y; c_X, \tau_X)$, 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 $\partial\pi_i/(\partial c_i) < 0 < \partial\pi_i/(\partial c_j)$ and $\partial\pi_i/(\partial\tau_i) < 0 < \partial\pi_i/(\partial\tau_j)$ hold for $i, j \in \{X, Y\}$ and $i \neq j$.

In Stage 1, given $c_i \in \{\overline{c}, \underline{c}\}$ and $c_j \in \{\overline{c}, \underline{c}\}$, the two firms simultaneously decide whether to undertake FDI. Let $s_h \in \{E, I\}$ denote Firm h's action. Note that $\tau_h = 0$ if $s_h = I$ and $\tau_h > 0$ if $s_h = E$ ($h \in \{X, Y\}$). If Firm h undertakes FDI, it must incur the fixed cost of FDI, F_h, in each time. If Firm i has yet to adopt the new technology, its gain from FDI (gross of the fixed cost of FDI) is given by $\overline{\Omega}_i(c_j, s_j) := \pi_i(\overline{c}, 0; c_j, \tau_j) - \pi_i(\overline{c}, \tau_i; c_j, \tau_j)$. If Firm i has already adopted the new technology, its gain from FDI is given by $\underline{\Omega}_i(c_j, s_j) := \pi_i(\underline{c}, 0; c_j, \tau_j) - \pi_i(\underline{c}, \tau_i; c_j, \tau_j)$. Each firm's gains from FDI depends not only on its own production technology but also on the rival's technology and the location choice. A firm that does not adopt the new technology chooses FDI if $\overline{\Omega}_i(c_j, s_j) > F$ holds, and exporting otherwise. A firm that adopts the new technology chooses FDI if $\underline{\Omega}_i(c_j, s_j) > F$ holds, and exporting otherwise. The same calculation is made for deriving $\overline{\Omega}_j(c_i, s_i)$ and $\underline{\Omega}_j(c_i, s_i)$.

Let $\widetilde{s}_i(c_i, c_j) \in \{E, I\}$ denote Firm i's equilibrium action given both firms' unit production costs and let $(\widetilde{s}_i(c_i, c_j), \widetilde{s}_j(c_j, c_i))$ denote the equilibrium location choices. TA changes the production cost, and therefore affects the equilibrium location of each firm. Without loss of generality, we suppose Firm i is the "first adopter," who adopts the new technology first and Firm j is the "second adopter," who adopts it after Firm i. Let there be three time phases. In Phase 1, neither firm adopts the new technology. In Phase 2, only the first adopter adopts the new technology. In Phase 3, both firms adopt the new technology. We do not rule out the possibility that both firms adopts the new technology at the same

[7] 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, c_Y, τ_X, and τ_Y.

timing, so there might not be Phase 2 in an equilibrium.

At the beginning of the game, the firms choose the time for new technology adoption anticipating its effects on the location decisions in Stage 1.

Let $\overline{\pi}_i(c_j)$ and $\underline{\pi}_i(c_j)$ respectively denote Firm i's ($i \in \{X, Y\}$) instantaneous profits before and after TA. These profits depend on the rival's production cost, c_j ($j \neq i$). Furthermore, let T_i denote Firm i's timing of TA. As we have assumed earlier, Firm i is the first and Firm j the second adopter. Therefore, $T_i \leq T_j$ holds. Because $\overline{\pi}_i(c_j)$ and $\underline{\pi}_i(c_j)$ are independent of t, the discounted sum of the first adopter's profits, net of the cost of TA, is given by

$$\Pi_i(T_i, T_j) = \int_0^{T_i} e^{-rt}\overline{\pi}_i(\overline{c})\,dt + \int_{T_i}^{T_j} e^{-rt}\underline{\pi}_i(\overline{c})\,dt + \int_{T_j}^{\infty} e^{-rt}\underline{\pi}_i(\underline{c})\,dt - e^{-rT_i}K(T_i), \tag{8}$$

and the discounted sum of the second adopter's profits is given by

$$\Pi_j(T_j, T_i) = \int_0^{T_i} e^{-rt}\overline{\pi}_j(\overline{c})\,dt + \int_{T_i}^{T_j} e^{-rt}\overline{\pi}_j(\underline{c})\,dt + \int_{T_j}^{\infty} e^{-rt}\underline{\pi}_j(\underline{c})\,dt - e^{-rT_j}K(T_j). \tag{9}$$

By solving $d\Pi_i(T_i, T_j)/dT_i = 0$ and $d\Pi_j(T_j, T_i)/dT_j = 0$, the equilibrium times of TA are determined. Let $\Delta\pi_i \equiv \underline{\pi}_i(\overline{c}) - \overline{\pi}_i(\overline{c})$ and $\Delta\pi_j \equiv \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\underline{c})$ respectively denote the first and the second adopters' gains from TA. The following proposition explains a general property of the equilibrium.

Proposition 3 *The equilibrium times of technology adoption satisfy* $\widetilde{T}_i < \widetilde{T}_j$ *if* $\Delta\pi_i > \Delta\pi_j$ *holds, and* $\widetilde{T}_i = \widetilde{T}_j$ *if both* $\Delta\pi_i \leq \Delta\pi_j$ *and* $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) = \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ *hold.*

If $\Delta\pi_i \leq \Delta\pi_j$ holds, then the second adopter adopts the new technology at the same time as the first adopter does. This means that both firms' marginal costs decrease from $\overline{c}$ to $\underline{c}$. Thus, if $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) = \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ holds, both firms' marginal gains from the simultaneous TA coincide, and the simultaneous TA, $\widetilde{T}_i = \widetilde{T}_j$, becomes an equilibrium outcome. However, if $\Delta\pi_i \leq \Delta\pi_j$ and $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) \neq \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ hold, the marginal gains from the simultaneous TA differ between the two firms, contradicting the supposition that both firms adopts the new technology at the same time. In this case, the simultaneous TA cannot be an equilibrium outcome. If $\widetilde{T}_i < \widetilde{T}_j$ holds, the equilibrium times of TA satisfy

$$\Delta\pi_i = rK(\widetilde{T}_i) - K'(\widetilde{T}_i) \text{ and } \Delta\pi_j = rK(\widetilde{T}_j) - K'(\widetilde{T}_j). \tag{10}$$

In this case, the time periods in $t \in [0, \widetilde{T}_i)$ constitute Phase 1, where both firms use the old technology; those in $t \in [\widetilde{T}_i, \widetilde{T}_j)$ constitute Phase 2 where only Firm i uses the new technology; and those in $t \in [\widetilde{T}_j, \infty)$ constitute Phase 3, where both firms use the new technology. When $\widetilde{T}_i = \widetilde{T}_j$ holds, however, both firms choose the same time for TA such that it satisfies

$$\Delta\widehat{\pi} = \underline{\pi}_i\,(\underline{c}) - \overline{\pi}_i\,(\overline{c}) = \underline{\pi}_j\,(\underline{c}) - \overline{\pi}_j\,(\overline{c}) = rK(\widetilde{T}_i) - K'(\widetilde{T}_i). \tag{11}$$

In this case, there are no Phase-2 periods, and both firms adopt the new technology at the same time.

3.2 Multilateral liberalization of FDI

In what follows, we discuss the effects of improving market access. Let us first analyze the case with $F_X = F_Y = F \geq 0$ and $\tau_X = \tau_Y = \tau \geq 0$; that is, both firms face the same fixed cost of FDI and the same trade cost. We can rank the gains from FDI as summarized in Lemma 1.

Lemma 1 *Given $\tau_X = \tau_Y = \tau > 0$, we have (i) $\overline{\Omega}_i(c_j, E) > \overline{\Omega}_i(c_j, I)$ and $\underline{\Omega}_i(c_j, E) > \underline{\Omega}_i(c_j, I)$ if evaluated at the same $c_j \in \{\overline{c}, \underline{c}\}$ and (ii) $\underline{\Omega}_i(\overline{c}, s_j) > \underline{\Omega}_i(\underline{c}, s_j) > \overline{\Omega}_i(\overline{c}, s_j) > \overline{\Omega}_i(\underline{c}, s_j)$ if evaluated at the same $s_j \in \{E, I\}$. Properties (i) and (ii) are applied to Firm j's gains from FDI.*

This lemma implies that (i) both firms' gains from undertaking FDI decrease if the rival firm also undertakes FDI, meaning that the two firms' FDIs are strategic substitutes; (ii) regardless of the rival's cost, a firm's gains from FDI increase after TA, and given a firm's own technology, the gains from FDI are higher when the rival has not adopted the new technology.

Combining (i) and (ii) of Lemma 1, we have $\underline{\Omega}_i(\overline{c}, E) > \underline{\Omega}_i(\underline{c}, E) = \underline{\Omega}_j(\underline{c}, E) > \overline{\Omega}_i(\overline{c}, E) = \overline{\Omega}_j(\overline{c}, E) > \overline{\Omega}_i(\overline{c}, I) = \overline{\Omega}_j(\overline{c}, I) > \overline{\Omega}_j(\underline{c}, I)$ and $\underline{\Omega}_i(\overline{c}, I) > \underline{\Omega}_i(\underline{c}, I) = \underline{\Omega}_j(\underline{c}, I) > \overline{\Omega}_i(\overline{c}, I) = \overline{\Omega}_j(\overline{c}, I)$. Although the ranking between $\overline{\Omega}_j(\underline{c}, E)$ and $\underline{\Omega}_i(\overline{c}, I)$ is ambiguous, we focus only on the case where $\underline{\Omega}_i(\overline{c}, I) > \overline{\Omega}_j(\underline{c}, E)$ holds to rule out multiple location equilibria when one firm adopts new technology but the other firm does not.[8] Furthermore, the ranking between $\overline{\Omega}_i(\overline{c}, E)$ and $\underline{\Omega}_i(\underline{c}, I)$ is also ambiguous, where $\overline{\Omega}_i(\overline{c}, E) < \underline{\Omega}_i(\underline{c}, I)$ holds if τ is small enough to satisfy $\tau < \overline{c} - \underline{c}$ and $\overline{\Omega}_i(\overline{c}, E) \geq \underline{\Omega}_i(\underline{c}, I)$ holds otherwise.[9]

Figure 5 depicts the equilibrium firms' possible locations in the (τ, F) space.

[Figure 5 about here]

Figure 5 indicates eight possible patterns of location choices in the three phases of TA. Table 1 summarizes the equilibrium locations in these cases.

[Table 1 about here]

[8]If $\overline{\Omega}_j(\underline{c}, E) \geq \underline{\Omega}_i(\overline{c}, I)$ holds, there exists a case in the Phase-2 equilibrium where one of the two firms undertakes FDI while the other chooses exporting, so that which firm becomes the FDI firm is irrelevant. That is, either the first (Firm i) or the second (Firm j) adopter can be the FDI firm in Phase 2 under the same parameter values. With a linear-demand, $\underline{\Omega}_i(\overline{c}, I) > \overline{\Omega}_j(\underline{c}, E)$ holds if $\overline{c} - \underline{c} \geq \tau/3$ holds.

[9]Since we have $\overline{\Omega}_i(\overline{c}, E) - \underline{\Omega}_i(\underline{c}, I) = 4\tau\{\tau - (\overline{c} - \underline{c})\}/9b$, $\overline{\Omega}_i(\overline{c}, E) \geq \underline{\Omega}_i(\underline{c}, I)$ holds if $\tau \geq \overline{c} - \underline{c}$ and $\overline{\Omega}_i(\overline{c}, E) < \underline{\Omega}_i(\underline{c}, I)$ holds if $\tau < \overline{c} - \underline{c}$.

Given the location choices in stage 1, a firm determines the time of TA at the initial period. The two firms' equilibrium times of TA depend on their gains from TA, $\Delta\pi_i$ and $\Delta\pi_j$.

To explore the effect of multilateral liberalization of FDI, let F^0 and τ^0 denote the initial level (Point A in Figure 5) and define the cutoff fixed cost levels, given τ^0, as $\underline{F}(\overline{c}, E) = \underline{\Omega}_i(\overline{c}, E)$, $\underline{F}(\underline{c}, E) = \underline{\Omega}_i(\underline{c}, E) = \underline{\Omega}_j(\underline{c}, E)$, $\underline{F}(\underline{c}, I) = \underline{\Omega}_i(\underline{c}, I) = \underline{\Omega}_j(\underline{c}, I)$, $\overline{F}(\overline{c}, E) = \overline{\Omega}_i(\overline{c}, E) = \overline{\Omega}_j(\overline{c}, E)$, $\overline{F}(\overline{c}, I) = \overline{\Omega}_i(\overline{c}, I) = \overline{\Omega}_j(\overline{c}, I)$, and $\overline{F}(\underline{c}, I) = \overline{\Omega}_j(\underline{c}, I)$. We have $\underline{F}(\overline{c}, E) > \underline{F}(\underline{c}, E) > \underline{F}(\underline{c}, I) > \overline{F}(\overline{c}, E) > \overline{F}(\overline{c}, I) > \overline{F}(\underline{c}, I)$. Since $\tau^0 < \overline{c} - \underline{c}$, we focus on the situation where TA reduces each foreign firm's unit cost to supply its product more than FDI does.

Starting from $F = F^0 > \underline{F}(\overline{c}, E)$, the gradual reduction of F to $F = 0$ changes the equilibrium location choices. Figure 6 depicts how each firm's gains from TA change as F decreases. In Figure 6, the upper diagram shows the gains from TA when the market size of the domestic country, a, is small and the technology gap between the new and the old technology, $\overline{c} - \underline{c}$, is large. The lower diagram in Figure 6 shows the gains from TA when a is large and $\overline{c} - \underline{c}$ is small. In those diagrams, the solid line represents the first adopter's gains from TA (i.e., $\Delta\pi_i$), while the dashed line represents the second adopter's gains from TA (i.e., $\Delta\pi_j$). By (10) and (11), the greater the marginal gains from TA, the earlier the equilibrium time for TA occurs. The detailed derivations of the marginal gains from TA and the equilibrium timings of TA are provided in the Appendix A.6.

[**Figure 6 about here**]

Hereafter, we compare the equilibrium timing of TA. Suppose the lower bound of the cost of adoption, $\underline{K}$, is small enough for Firm X to always adopt the new technology at some point in time.

3.2.1 The first adopter's gains from technology adoption

Let us first examine how the reduction of F changes the first adopter's marginal gains from TA, $\Delta\pi_i$. Within Region I, TA by the first adopter does not changes the equilibrium locations, and both firms choose exporting both before and after the first adopter's TA. Therefore, the liberalization of FDI does not affect the marginal gains from TA, and TA reduces only the first adopter's marginal cost of production. In Regions II, III, and IV, both firms choose exporting in Phase 1. TA induces the first adopter to undertake FDI in Phase 2, while the second adopter continues to choose exporting in Phase 2. In these regions, TA not only reduces its marginal cost but also generates a location equilibrium favorable to the first adopter. Here, the marginal gains from TA increase as F decreases.

If the fixed cost of FDI is reduced and it is in Region V, FDI becomes profitable for one of the two firms even before the first adopter's TA. Therefore, the equilibrium locations become either (I, E) or

(E, I) in Phase 1. However, the Phase-2 location is still (I, E). This implies that if the location in Phase 1 is (E, I), TA by the first adopter may cause an "FDI conversion effect" that changes the second adopter's FDI in Phase 1 into the first adopter's FDI in Phase 2. If the FDI conversion occurs, the first adopter's marginal gains from TA jump up because the TA by the first adopter has a strategic effect that drives out the rival's FDI and replaces it with its own. If the location equilibrium in Phase 1 is (I, E), the first adopter undertakes FDI in both phases, and FDI conversion does not occur. In this case, the marginal gains from TA do not rise, but remain constant throughout Region V.

In Region VI, the fixed cost of FDI becomes low enough to induce both firms to undertake FDI in Phase 1, and the equilibrium location moves to (I, I). After the first adopter implements TA, a technology gap emerges between the two firms, and the inefficient firm's (i.e., the second adopter's) FDI is blocked in Phase 2. This implies that the first adopter obtains not only a cost advantage but also a location advantage over the rival firm in Phase 2. We call the effect an "FDI blockig effect." Thus, the first adopter's marginal gains from TA reaches the highest level across all regions.

In Region VII, where the fixed cost is almost eliminated, both firms always undertake FDI in all three phases. The first adopter's TA reduces only its marginal cost of production and does not affect the firms' location choices. The marginal gains from TA in Region VII are lower than those in Region VI, but are higher than the marginal gains in Region I.

3.2.2 The second adopter's gains from technology adoption

Next, let us examine the effect of the reduction in F on the second adopter's gains from TA. In Region I, both firms always choose exporting and the second adopter's TA reduces only its marginal cost of production. The marginal gains from TA are lower for the second than the first adopter, because the gains from TA are lower as the rival's marginal cost decreases. Therefore, the two firms' TAs are strategic substitutes and $\Delta\pi_j < \Delta\pi_i$ holds in this region.

In Region II, the first adopter undertakes FDI in Phase 2 because it has a technological advantage over the second adopter. However, once the second adopter adopts the new technology and the technology gap between the firm is closed in Phase 3, both firms choose exporting. This implies that the second adopter's TA has a strategic effect of blocking the rival's FDI, made before the TA. Due to this additional benefit, the second adopter's gains from TA jump up from the level in Region I.

Here, the ranking between $\Delta\pi_j$ and $\Delta\pi_i$ becomes ambiguous. We can confirm that $\Delta\pi_i > \Delta\pi_j$ holds if the technology gap between the new and old technologies, $\bar{c} - \underline{c}$, is large and the market size of the domestic country, a, is small. This case is depicted in the upper diagram of Figure 6. However, if $\bar{c} - \underline{c}$, is small and a is large, $\Delta\pi_i \leq \Delta\pi_j$ is possible in Region II, as is depicted in the lower diagram of Figure 6. The two firms choose the same locations in Phases 1 and 3 and $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\bar{c}) = \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\bar{c})$

holds in this region. By Proposition 3, this means that both firms adopt the new technology at the same timing and the equilibrium locations remain (E, E) despite the simultaneous adoption of the new technology by the two firms. In this case, each firm expects its rival to simultaneously adopt the new technology in response to its own TA, thereby reducing the marginal gains from TA. The marginal gains decline because the simultaneous TA generates gains neither for the first adopter (from the technological advantage over the rival) nor for the second adopter (from closing the technology gap).

Lemma 2 *If the technology gap is small and the market size of the domestic country is large, multilateral liberalization of FDI may lower the gains from technology adoption for both firms.*

In Region III, the first adopter undertakes FDI in Phase 2 as well, and one of the two firms undertakes FDI in Phase 3. Hence, if (E, I) represents the equilibrium locations in Phase 3, the second adopter's TA has an FDI conversion effect that drives out the FDI of the first adopter and replaces it with that of the second. In this case, the second adopter's marginal gains from TA rise even higher than the Region II level, increasing as F declines. However, if (I, E) represents the equilibrium locations in Phase 3, the second adopter's TA does not affect the firms' locations, and the first mover remains the FDI firm. In this case, the marginal gains from TA decrease below the initial level in Region I, although they remain higher than the gains from TA when both firms simultaneously adopt the new technology in Region II.

If F decreases such that it falls into either Regions IV, V, or VI, the second adopter's TA induces FDI as well without blocking the rival's FDI. Here, the marginal gains from TA remain higher than the lower level of gains in Region III, increasing as F declines.

Once F is low enough to be in Region VII, both firms always choose FDI. The gains from TA in this region are higher than the initial level. However, whether they increase above the higher level of gains in Regions II and III is ambiguous. We can confirm that the marginal gains in Region II or Region III are higher than those in Region VII when the market size is large and the technology gap is small.[10]

3.2.3 The equilibrium timings of TA

We have examined the effects of multilateral liberalization of FDI on the two firms' marginal gains from TA. The following proposition summarizes the equilibrium times of TA.

Proposition 4 *Given the level of trade costs, multilateral liberalization of FDI may make the equilibrium time of technology adoption either quicker or slower. Technology adoption by the first adopter is quickest when* $F \in [\overline{F}(\underline{c}, I), \overline{F}(\overline{c}, I)]$ *holds. Technology adoption by the second adopter is quickest (i) at* $F = \underline{F}(\underline{c}, I)$ *if* $a > \overline{c} + 3(\overline{c} - \underline{c}) - \tau/2$ *holds and the adoption causes an FDI conversion effect, (ii) at* $F = \underline{F}(\underline{c}, E)$

[10]Specifically, the marginal gains from TA in Region II are higher than those in Region VII if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau/2\}$ holds, and the marginal gains in Region III are higher than the gains in Region VII if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) - \tau/2\}$ holds.

if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau/2\}$ *holds and the adoption blocks the first adopter's FDI but does not causes an FDI conversion effect, and (iii) when* $F \in [0, \overline{F}(\underline{c}, I)]$ *holds otherwise, under which both firms always undertake FDI.*

Proposition 4 suggests that when two foreign firms compete in the domestic market, the relationship between FDI liberalization and the timing of TA becomes much more complicated. A reduction in F basically drives FDI by both firms, but the effect on the first adopter's post-TA FDI is greater. Hence, from the first adopter's viewpoint, the gains from TA is maximized if the TA has an FDI blocking effect (Region VI). From the second adopter's viewpoint, if F decreases to promote FDI by the first adopter in Phase 2 but remains high enough to block both firms' FDI in Phase 3 (Region II), FDI liberalization provides an additional incentive to the second adopter to implement the new technology, considering that the rival's supply mode changes from FDI to exporting with TA. In addition to the FDI blocking effect, a further reduction in F may induce FDI by the second adopter in Phase 3, further increasing the gains further (Region III). At the same level of F, however, if the first adopter, but not the second adopter, becomes the FDI firm in Phase 3, the second adopter's gains from TA become lower than those in Region I, where both firms always choose exporting.

If F becomes sufficiently low to ensure that the first adopter undertakes FDI in all periods (Regions IV, V, and VI), TA no longer has an FDI conversion effect, and induces FDI by the second adopter in Phase 3. In this case, the level of F determines whether the reduction from F^0 speeds up TA. If F becomes low enough to ensure that both firms undertake FDI in all periods (Region VII), TA is always earlier than the timing at the initial fixed cost level. However, if the market size is large and the cost reduction by TA is small, the adoption is slower than the timing at the middle range of F, where TA has an FDI conversion effect or an FDI blocking effect. Otherwise, the timing of TA is quickest when the fixed cost is sufficiently low to ensure that both firms implement FDI in all three phases.

3.3 Multilateral trade liberalization

This section considers the effect of multilateral trade liberalization. The initial level of the fixed cost of FDI and the initial level of trade cost are set at F^1 and τ^1, respectively (see Point B in Figure 5). Initially, $\overline{\Omega}_j(\underline{c}, I) > F^1$ holds such that both firms always choose FDI in all phases. Since the gains from FDI are increasing in τ, we can find the cut-off level of trade cost above which a firm chooses FDI given $F = F^1$. The cut-off level depends on the rival's technological condition and its location choice. Let $\overline{\tau}(\underline{c}, I)$, $\overline{\tau}(\overline{c}, I)$, $\overline{\tau}(\overline{c}, E)$, $\underline{\tau}(\underline{c}, I)$, $\underline{\tau}(\underline{c}, E)$, and $\underline{\tau}(\overline{c}, E)$ respectively denote the cut-off levels of trade cost that satisfy $\overline{\Omega}_j(\underline{c}, I) = F^1$, $\overline{\Omega}_i(\overline{c}, I) = \overline{\Omega}_j(\overline{c}, I) = F^1$, $\overline{\Omega}_i(\overline{c}, E) = \overline{\Omega}_j(\overline{c}, E) = F^1$, $\underline{\Omega}_i(\underline{c}, I) = \underline{\Omega}_j(\underline{c}, I) = F^1$, $\underline{\Omega}_i(\underline{c}, I) = \underline{\Omega}_j(\underline{c}, I) = F^1$, $\underline{\Omega}_i(\underline{c}, E) = \underline{\Omega}_j(\underline{c}, E) = F^1$, and $\underline{\Omega}_i(\overline{c}, E) = F^1$. As shown in Figure 5,

$\underline{\tau}(\bar{c},E) < \underline{\tau}(\underline{c},E) < \underline{\tau}(\underline{c},I) < \overline{\tau}(\bar{c},E) < \overline{\tau}(\bar{c},I) < \underline{\tau}(\bar{c},E)$ holds. The initial trade cost satisfies $\overline{\tau}(\underline{c},I) < \tau^1$.

Starting from τ^1, as the trade cost is multilaterally reduced, the equilibrium locations change step-by-step from the patterns in Region VII to those in Region I. Figure 7 depicts the relationship between τ and the gains from TA when the market size of the domestic country is small and the technology gap between the new and the old technology is large. Appendix A.6 provides the detailed description for each region.

[**Figure 7 about here**]

As in the multilateral reduction of the fixed cost for FDI, the gains from TA for the first adopter is highest in Region VI, where the first mover's TA has an additional effect that drives out the second adopter's FDI in Phase 2. The second adopter's gains from TA in Regions II and III may be higher than those at the original level of trade cost, $\tau = \tau^1$. In Region II and Region III, the second adopter's TA blocks the first adopter's TA in Phase 3, giving the second adopter an additional gain from TA. We have the following proposition.

Proposition 5 *Given the fixed cost of FDI, if two foreign firms serve the domestic market, multilateral liberalization of trade may make the equilibrium time of technology adoption either quicker or slower. Technology adoption by the first adopter is quickest when $\tau = \overline{\tau}(\underline{c},I)$ holds. Technology adoption by the second adopter is most rapid (i) at $\tau = \tau^*$ that satisfy $\tau^* \in (\underline{\tau}(\bar{c},E), \underline{\tau}(\underline{c},I)]$ if the market size is large and the technology gap is small, under which the second adopter's technology adoption causes an FDI conversion effect or an FDI blocking effect, (ii) when $\underline{\tau}(\bar{c},E) < \tau$ or $\tau = 0$ hold otherwise, under which both firms make tariff-free access to the domestic market.*

Here, trade liberalization either encourages or discourages TA, as in a single-firm model. However, given that TA has an additional effect of driving out the rival's FDI in the middle range of the trade cost, the timing of TA may not be the most rapid under free trade for both the foreign firms.

3.4 Preferential liberalization of FDI

We have shown that multilateral liberalization of both FDI and trade may not accelerate the firms' TA. Let us next analyze the case with $F_X \neq F_Y$ and $\tau_X \neq \tau_Y \geq 0$, that is, where firms face different fixed costs of FDI and different trade costs. This situation corresponds to one where the domestic country concludes a bilateral investment treaty or a preferential trade agreement with one of the two foreign countries.

However, if we consider different fixed costs and trade costs simultaneously, we would have a substantial number of location patterns, depending on the levels of four parameters: F_X, F_Y, τ_X and τ_Y.

To make a meaningful comparison between preferential liberalization and multilateral liberalization, we should only discuss the preferential liberalization of FDI, given that the two firms face the same level of trade costs, $\tau_X = \tau_Y$, in exporting. We then compare the gains from TA under preferential versus multilateral liberalization of FDI.

Let us suppose that the initial level of fixed costs and trade costs satisfy $F_X = F_Y = F^0$ and $\tau_X = \tau_Y = \tau^0$; that is, the starting point is the same as in multilateral liberalization. We then consider preferential reduction of F_X where $F_Y = F^0$ and $\tau_X = \tau_Y = \tau^0$ are kept fixed.

Since $F_Y = F^0 > \underline{F}(\bar{c}, E)$ holds, firm Y always chooses exporting irrespective of technological conditions and firm X's location choices. Firm X's gains from undertaking FDI are calculated on the assumption that Firm Y chooses exporting (i.e., $s_Y = E$): $\overline{\Omega}_X(\bar{c}; E)$, $\overline{\Omega}_X(\underline{c}; E)$, $\underline{\Omega}_X(\bar{c}; E)$, and $\underline{\Omega}_X(\underline{c}; E)$. Figure 7 depicts the possible location outcomes in five cases, Region i to Region v. By Lemma 1, $\underline{\Omega}_X(\bar{c}; E) > \underline{\Omega}_X(\underline{c}; E) > \overline{\Omega}_X(\bar{c}; E) > \overline{\Omega}_X(\underline{c}; E)$ holds given $\tau_X = \tau_Y > 0$.[11] We define the cutoff levels of the fixed cost, given τ^0, as $\underline{F}_X(\bar{c}, E) = \underline{\Omega}_X(\bar{c}; E)$, $\underline{F}_X(\underline{c}, E) = \underline{\Omega}_X(\underline{c}; E)$, $\overline{F}_X(\bar{c}, E) = \overline{\Omega}_X(\bar{c}; E)$, and $\overline{F}_X(\underline{c}, E) = \overline{\Omega}_X(\underline{c}; E)$. Clearly, $\underline{F}_X(\bar{c}, E) > \underline{F}_X(\underline{c}, E) > \overline{F}_X(\bar{c}, E) > \overline{F}_X(\underline{c}, E)$ holds.

[**Figure 8 about here**]

The effects of F reduction on the gains from TA depend on whether firm X, which experiences preferential reduction of the fixed costs for FDI, is the first or the second adopter. Table 2 represents the equilibrium locations in each case.

[**Table 2 about here**]

3.4.1 Preferential liberalization targeting the first adopter

Suppose that Firm X is the first adopter (see Figure 9). The bold solid line in the figure represents Firm X's gains from TA and the bold dashed line is Firm Y's gains from TA. The non-bold solid and the dashed lines respectively represent the first adopter's and the second adopter's gains from TA in the case of multilateral liberalization.

[**Figure 9 about here**]

In Region i of Figure 9, both firms always choose exporting, and the equilibrium locations and timing of TA are the same as those with multilateral liberalization. In Region ii, Firm X chooses FDI in Phase 2 and it chooses exporting in Phase 1 and Phase 3. This means that Firm Y's TA blocks Firm X's TA,

[11] The detailed comparision of the cut-off levels is provided in Appendix A.10.

similar to Region II in multilateral liberalization. In this region, therefore, preferential liberalization has the same effect as multilateral liberalization.

In Region iii, Firm X's gains from FDI is the same as those of the first adopter in multilateral liberalization. However, since $F_X < \underline{F}_X(\underline{c}, E)$ holds, Firm X always undertakes FDI while Firm Y always chooses exporting in Phases 2 and 3. Since Firm Y has a location disadvantage, Firm Y's gains from TA decrease from the initial level, and are given by $\Delta\pi_Y = \pi_Y(\underline{c}, \tau; \underline{c}, 0) - \pi_Y(\overline{c}, \tau; \underline{c}, 0)$, which coincide with the lower level of the second adopter's gains from TA in multilateral liberalization. The situation does not change in Regions iv and v, meaning that the second adopter's gains from TA in preferential liberalization are weakly lower than those in multilateral liberalization, as long as the firm targeted by preferential liberalization becomes the first adopter.

In Regions iv and v, Firm X chooses FDI and Firm Y exporting in all phases. In this case, Firm X's gains from TA are lower than those in Regions V and VI with multilateral liberalization. With multilateral liberalization of FDI, the first adopter's TA gives the firm an additional gain by blocking the second adopter's FDI. Since the second adopter always chooses exporting in preferential liberalization, the first adopter's TA does not generate this additional gain. However, both firms always choose FDI in multilateral liberalization (Region VII of Figure 6) while Firm X is still the sole FDI firm in preferential liberalization if the fixed cost is close to zero. This means that the gains from TA in preferential liberalization are higher than those in multilateral liberalization if F is small enough.

Proposition 6 *Preferential liberalization of FDI targeting the first adopter always makes the timing of technology adoption earlier for the first adopter. For the first adopter, the equilibrium timing of TA occurs earlier in preferential compared to multilateral liberalization if the fixed cost is sufficiently low. Otherwise, the first adopter's TA is weakly earlier in multilateral liberalization. Preferential liberalization always leads to slower timing of technology adoption by the second adopter.*

Because of its discriminatory nature, preferential liberalization discourages TA by a firm not targeted by liberalization. We call this the *technology diversion effect.* In contrast, preferential liberalization always encourages TA by the eligible firm, as a result of the *technology creation effect.* Therefore, the former effect prolongs the time to reach Phase 3 and the latter effect shortens the length of Phase 1.

We have shown that although preferential liberalization seems to work well for the eligible firm, multilateral liberalization favors the first adopter for promotion of TA unless the fixed cost of FDI is sufficiently low. This suggests that preferential liberalization of FDI targeting the first adopter has a limited role in promoting TA.

3.4.2 Preferential liberalization targeting the second adopter

Next, we examine the case where Firm X is the second adopter (see Figure 10).

[**Figure 10 about here**]

In Regions i, ii, and iii, TA by Firm Y (the first adopter) does not change the location equilibrium, and both firms choose exporting in Phases 1 and 2. Therefore, the first adopter's gains from TA do not change. In Region iv, Firm X (the second adopter) undertakes FDI in Phase 1 and the first adopter's TA blocks Firm X's FDI in Phase 2. Because of this FDI blocking effect, the first adopter's gains from TA are higher in Region iv than those in Regions i to iii. However, if F_X is sufficiently low and it is in Region v, Firm X always undertakes FDI, while the weak location equilibrium position of Firm Y makes its gains from TA lower than those in Regions i to iii.

With regard to firm X as the second adopter targeted by preferential liberalization, its gains from TA in Regions i and ii remain unchanged with the reduction in F_X. In Regions iii and iv, TA induces Firm X to undertake FDI in Phase 3. Since its post-FDI profit increases as F_X decreases, preferential liberalization increase Firm X's gains from TA in these regions. In region v, firm X always undertakes FDI and the gains from TA reach the highest level and does not depend on F_X.

Because of firm X's strong position in location equilibrium, we found that firm X's gains from TA may exceed Firm Y's gains in Region iv and/or Region v, $\Delta\pi_X \geq \Delta\pi_Y$ (see Appendix A.12 for details). If $\Delta\pi_X \geq \Delta\pi_Y$ holds, Proposition 3 states that Firm X cannot be the second, and therefore becomes the first, adopter in these regions in equilibrium.

Figure 10 depicts the case where $\Delta\pi_Y > \Delta\pi_X$ holds in all regions. As Figure 10 shows, the non-eligible first adopter's gains from TA drops below the levels in multilateral liberalization because of the technology diversion effect. With regard to the second adopter as the target of the preferential liberalization, the technology creation effect makes its gains from TA higher in Region iv, though they are lower in Region ii and can be still lower in Region iii. Preferential liberalization may even transform the second adopter into the first adopter. The second adopter attains the highest possible gains from TA at any F_X that satisfies $F_X \leq \overline{F}_X(\underline{c}, E)$.

Proposition 7 *Preferential liberalization of FDI always speeds up technology adoption by the second adopter targeted by it. The equilibrium timing of technology adoption by the second adopter may be earlier in preferential than multilateral liberalization in the range of the fixed costs for FDI where the second adopter's technology adoption promotes its FDI. Preferential liberalization always delays technology adoption by the first adopter. It can even transform the second adopter into the first adopter.*

Unlike preferential liberalization of FDI targeting the first adopter, preferential liberalization targeting the second adopter closes the gap between the two firms gains from TA and cuts the time to reach Phase 3, in which both firms adopt the new technology. Preferential liberalization can speed up the timing of TA for the second adopter than multilateral liberalization does. However, this positive effect on TA comes with a negative effect on the first adopter's TA, which prolongs the length of Phase 1, in which both firms produce with the old technology. These results suggest that preferential liberalization has both pros and cons in promoting TA.

4 Improving market access and consumer surplus

We have investigated the relationship between improving access to the domestic market and the times of TA for foreign firms. Here, we discuss whether the domestic government has an incentive to improve market access via FDI liberalization.[12]

Up to this point, we have not specified whether τ_X and τ_Y are tariffs that generate revenues for the domestic government or other trade costs such as transport costs. If they are tariffs, the domestic government can shift part of the foreign profits earned in the domestic market as a tariff revenue. Whether a tariff reduction improves the domestic welfare is generally ambiguous and depends on the shape of the demand curve, the pre-liberalized level of tariffs, and so on. Hence, considering the rent-shifting effect of tariff substantially complicates the analysis, and we would not yield a clear-cut result.

Therefore, this paper simply assumes τ_X and τ_Y as trade costs that do not generate any revenue for the domestic country. With this assumption, domestic welfare coincides with consumer surplus denoted by $CS(Q) = \int_0^Q P(x)dx - P(Q)Q$, which is increasing in the total sales, Q.

4.1 Liberalization of FDI with a single foreign firm

Let us start with a foreign monopoly model. Because the equilibrium level of Q is decreasing in c_X and τ_X, the equilibrium consumer surplus $CS(c_X, \tau_X)$ is also decreasing in c_X and τ_X. In section 2, we have seen that free access to the domestic market by the foreign monopolist promotes TA.

The foreign monopolist's FDI makes τ_X redundant and improves consumer surplus given c_X, $CS(c_X, 0) > CS(c_X, \tau_X)$. However, FDI also changes the monopolist's incentive to adopt the new technology. Proposition 1 states that a reduction of F_X always increases the gains from TA. Therefore, liberalization of FDI always improves the discounted sum of the domestic consumer surplus by promoting inward FDI that avoids τ_X, accelerating the foreign firm's TA, which reduces c_X. The discounted sum of the domestic

[12] As far as consumer surplus is concerned, the welfare effects of trade liberalization is basically the same as those of FDI liberalization.

consumer surplus is maximized when F_X is sufficiently reduced such that $F_X < \overline{F}_X$ holds. We have the following proposition.

Proposition 8 *If a single foreign firm serves the domestic market, the discounted sum of consumer surplus is maximized where F_X satisfies $F_X < \overline{F}_X$, at which point the foreign firm always undertakes FDI and the earliest timing of technology adoption is realized.*

The proposition implies that the domestic government always has an incentive to improve market access for the foreign monopolist if the government is concerned about the domestic consumer surplus.

4.2 Multilateral liberalization of FDI with two foreign firms

The effect of FDI liberalization on the domestic consumer surplus becomes much more complicated with two foreign firms. The equilibrium consumer surplus $CS(c_i, \tau_i; c_j, \tau_j)$ in the domestic country is decreasing in c_i, c_j, τ_i, and τ_i.

In the case of multilateral liberalization, if the market size is small enough and the technology gap large enough to satisfy $a \leq \bar{c} + 3(\bar{c} - \underline{c}) - \tau/2$ (see the upper diagram of Figure 6), the earliest timing of TA for the first adopter is realized anywhere in $\overline{F}(\underline{c}, I) \leq F \leq \overline{F}(\bar{c}, I)$, in which the first adopter's TA blocks the second adopter's FDI in Phase 2. The earliest timing of TA for the second adopter is realized anywhere in $0 \leq F \leq \overline{F}(\underline{c}, I)$. At an F level larger than $\overline{F}(\bar{c}, I)$, the timing of TA is postponed and FDIs are discouraged. Therefore, consumers always prefer $F \leq \overline{F}(\bar{c}, I)$ in this case. At $F = \overline{F}(\underline{c}, I)$, the location pattern in Region VI becomes the equilibrium outcome, and each firm realizes the earliest timing of TA. The Phase-2 consumer surplus in Region VI, however, is lower than that in Region VII because one of the two firms chooses exporting in Region VI while both firms undertake FDI in Region VII. If the lengths of the Phase-2 periods in Regions VI and VII are not substantially different, the consumers derives large benefits from the second adopter's FDI in Phase 2. If that is the case, the domestic government will set F at any level that satisfies $0 \leq F < \overline{F}(\underline{c}, I)$. Otherwise, it will set $F = \overline{F}(\underline{c}, I)$.

If the market size is small enough and the technology gap large enough to satisfy $a > \bar{c} + 3(\bar{c} - \underline{c}) - \tau/2$ (see the lower diagram of Figure 6) and the second adopter's TA causes the FDI conversion effect, the second adopter realizes the earliest timing of TA at $F = \underline{F}(\underline{c}, I)$. If the second adopter's TA does not cause an FDI conversion effect in Region III and $a > \bar{c} + 3\{(\bar{c} - \underline{c}) + \tau/2\}$ holds, the earliest timing of TA is realized at $F = \underline{F}(\underline{c}, E)$. If neither of the above inequalities holds, the same argument as the previous case is applied to this case. If the second adopter realizes the quickest timing of TA in Region III or Region II, the first adopter's TA is delayed relative to the TA in Region VI, but the second adopter's TA is also accelerated. This means that consumers can reach Phase 3 earlier and temporarily enjoy higher consumer surplus in Region II or Region III, though the Phase-1 consumer surplus and the Phase-3 consumer surplus in Region VI and Region VII are higher.

For instance, if $\Delta\pi_j > r\underline{K}$ holds in Region II or Region III and $\Delta\pi_j < r\underline{K}$ holds in Region VI and Region VII, the second adopter adopts the new technology in the former regions but it never does so in the latter regions. In this case, consumers reach Phase-3 equilibrium only if the fixed cost for FDI is high enough to fall into Region II or Region III. Although lower fixed cost realizes earlier TA for the first adopter and consumer surplus in Phase 1 and 2 is higher, the consumer may prefer Region II or Region III to enjoy the long-run gains from reaching Phase-3 equilibrium.

Proposition 9 *If two foreign firms serve the domestic market, multilateral liberalization of FDI may hurt domestic consumers.*

If firms do not choose the time of TA, multilateral liberalization of FDI promotes both firms' FDIs and never hurts domestic consumers. With endogenous TA by firms, multilateral liberalization may hurt consumers because it changes not only the firms' location choices but also the technology adoption timing of firms.

4.3 Multilateral liberalization versus preferential liberalization

Finally, we compare preferential liberalization of FDI with multilateral liberalization. We have shown that preferential liberalization basically has both the technology creation effect and the technology diversion effect.

The analysis in Section 3.4.1 suggests that preferential liberalization speeds up TA in Region v with $F < \overline{F}(\underline{c}, I)$ for only the first adopter targeted by preferential liberalization, but delays the second adopter's TA. Preferential liberalization is also inferior to multilateral liberalization in that it only promotes FDI by only the first adopter. In Region v with $F < \overline{F}(\underline{c}, I)$, the domestic country realizes higher consumer surplus during periods in which the first adopter has already adopted the new technology under preferential but not multilateral liberalization. Therefore, the domestic government, which seeks to maximize consumer surplus, prefers preferential liberalization only if the temporary increase in consumer surplus dominates the decreases in consumer surplus during other periods.

The analysis in Section 3.4.2 suggests that preferential liberalization, compared with multilateral liberalization, delays TA for the first adopter but may speed up TA for the second adopter targeted by preferential liberalization. Compared with multilateral liberalization, preferential liberalization cuts the time to reach Phase 3, meaning that consumers' gains from the second adopter's TA occur earlier. If these temporary gains are large enough, domestic consumers prefer preferential liberalization of FDI. For instance, if the lower bound of the fixed cost for TA is high enough for the second adopter to adopt the new technology only in preferential liberalization, the domestic government may choose preferential liberalization in order to reach the Phase-3 equilibrium, in which both firms adopt the new technology and higher consumer surplus is realized.

Proposition 10 *Preferential liberalization of FDI can provide a higher discounted sum of consumer surplus than multilateral liberalization does if the consumers' gains from earlier technology adoption by the targeted firm are large enough.*

In general, we cannot determine which type of liberalization results in higher consumers' welfare. Multilateral liberalization has an edge over preferential liberalization in that it both promote FDI by firms and generates the FDI conversion effect of TA. Nevertheless, preferential liberalization is more beneficial for domestic consumers in some cases because it preferentially accelerates the timing of TA of the target firms—an action that may generate sufficiently large consumer gains.

5 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 both pre- and post-adoption periods influence the foreign firms' incentives 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 attaining free trade or inducing horizontal FDI before and after technology adoption realizes the fastest timing of technology adoption. If two foreign firms compete in the domestic market, however, a reduction in both the fixed costs of FDI and the trade costs may delay technology adoption. The quickest timing of technology adoption may be attained when the fixed costs of FDI and the trade costs are neither very high nor very low. Although preferential liberalization of FDI always increases the gains from technology adoption for the targeted firm (the technology creation effect), multilateral liberalization may lead to greater gains because it causes the FDI conversion effect. Furthermore, the preferential liberalization causes the technology diversion effect to reduce the gains from technology adoption for the non-targeted firm. Consumers in the domestic country prefer preferential liberalization only if it speeds up the targeted firm's technology adoption and earlier technology adoption generates sufficiently large intertemporal gains.

This finding suggests that improved market access via multilateral liberalization of FDI or multilateral trade liberalization does not necessarily contribute to technological upgrading of firms. Preferential liberalization never prevents technology adoption by the targeted firm. However, it prevents technology adoption by the other firm, and the timing of technology adoption by the targeted firm can be even slower than the timing under multilateral liberalization. An unclear relationship between improving market access and technological advancements is consistent with the existing empirical findings. To assist technological developments of foreign firms, the fixed cost of FDI and the trade cost should be set such that technology adoptions generate additional gains by location changes in favor of the adopting firms.

Some directions remain for further research. First, we only focus on consumers' gains in evaluating the welfare effect of liberalizations. A full welfare analysis to consider tariff revenues and the profits of foreign firms would be important, though it would confound the already complicated analysis. Second, incorporating a licensing agreement between the firms into the model would be an interesting extension.

Third, we have assumed that, after technology adoption, there is no further technological progress. It is an interesting extension to consider a "technology ladder" to incorporate continuous adoption of superior technologies by firms. Also, the emergence of a new technology that renders the existing technology obsolete would be worth considering.[13]

Finally, considering technological spillover from the first adopter to the second adopter is an interesting extension. If technological spillover reduces the second adopter's unit cost to some degree, it will reduce its incentive to adopt state-of-the-art technology. If technological spillover reduces the cost of adopting new technology, it will basically speed up the second adopter's technology adoption. However, as is discussed in the paper, if the gap of the gains from technology adoption between the first adopter and the second adopter is eliminated by the spillover, it may reduce both firms' incentives to adopt the new technology because each firm recognizes that its technology adoption is immediately followed by that of the other firm. Although considering technological spillover is interesting, it is beyond the scope of this paper and is left for future research.

Appendix

A.1 Proof of Proposition 1

By (4), (5), and (6), a decrease in F_X increases $\Delta\pi_X$ for $F_X \in [\overline{\Omega}, \underline{\Omega})$. It does not affect $\Delta\pi_X$ otherwise. A shift from Region 1 to Region 2 changes $\Delta\pi_X$ as $\{\pi_X(\underline{c},0)-F_X\}-\pi_X(\bar{c},\tau_X)-[\pi_X(\underline{c},\tau_X)-\pi_X(\bar{c},\tau_X)] = \pi_X(\underline{c},0) - \pi_X(\underline{c},\tau_X) - F_X = \underline{\Omega} - F_X$, where $F_X \in [\overline{\Omega}, \underline{\Omega})$ holds. As $\Omega(\underline{c},\tau_X) > F$ holds, the shift increases $\Delta\pi_X$. A shift from Region 2 to Region 3 changes $\Delta\pi_X$ as $\pi_X(\underline{c},0) - \pi_X(\bar{c},0) - [\{\pi_X(\underline{c},0) - F_X\} - \pi_X(\bar{c},\tau_X)] = -[\pi_X(\bar{c},0) - \pi_X(\bar{c},\tau_X) - F_X] = -[\Omega(\bar{c},\tau_X) - F_X]$, where $F_X \in [\overline{\Omega}, \underline{\Omega})$ holds. As

[13] I thank a referee for pointing out these possible extensions.

$\overline{\Omega} \leq F_X$ holds, the shift increases $\Delta\pi_X$ if $\overline{\Omega} < F_X$ holds, but has no effect if $\overline{\Omega} = F_X$. Therefore, a decrease in F_X never delays the timing of technology adoption and the quickest timing of technology adoption is attained at any F_X that satisfies $F_X \leq \overline{\Omega}$. ■

A.2 Proof of Proposition 2

(i) If $\underline{\tau}_X < \tau_X$ holds, we have $\Delta\pi_X = \pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0)$ regardless of τ_X. This means that a decrease in τ_X does not change the equilibrium timing of technology adoption. (ii)If $\overline{\tau}_X < \tau_X \leq \underline{\tau}_X$ holds, we have $\Delta\pi_X = \{\pi_X(\underline{c}, 0) - F_X\} - \pi_X(\overline{c}, \tau_X)$ and a decrease in τ_X only increases the pre-adoption profit, $\pi_X(\overline{c}, \tau_X)$. This means that $\Delta\pi_X$ decreases with τ_X, delaying the timing of technology adoption. (iii) If $\tau_X < \overline{\tau}_X$ holds, we have $\Delta\pi_X = \pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$. 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 $\pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$ increases as τ_X decreases. At $\tau_X = \underline{\tau}_X$, $\pi_X(\underline{c}, 0) - \pi_X(\overline{c}, 0) = \{\pi_X(\underline{c}, 0) - F_X\} - \pi_X(\overline{c}, \tau_X)$ holds by the definition of $\underline{\tau}_X$. By the definition of $\overline{\tau}_X$, $\{\pi_X(\underline{c}, 0) - F_X\} - \pi_X(\overline{c}, \tau_X) = \pi_X(\underline{c}, \tau_X) - \pi_X(\overline{c}, \tau_X)$ holds at $\tau_X = \overline{\tau}_X$. Therefore, $\Delta\pi_X$ does not change discretely by a reduction in trade costs. ■

A.3 Proof of Corollary 1

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

A.4 Proof of Proposition 3

Remember that we define Firm i as the first adopter and Firm j as the second adopter. By definition, $T_i \geq T_j$ always holds. By (8) and (9), we have $\Pi_i'(T_i) = -e^{-rT_i}[\Delta\pi_i - \{rK(T_i) - K'(T_i)\}]$ and $\Pi_j'(T_j) = -e^{-rT_j}[\Delta\pi_j - \{rK(T_j) - K'(T_j)\}]$. Let $\widetilde{T}_i$ be the timing of TA that satisfies $\Pi_i'(\widetilde{T}_i) = 0$. Then, $\Delta\pi_i = rK(\widetilde{T}_i) - K'(\widetilde{T}_i)$ holds. If we evaluate $\Pi_j'(T_j)$ at $T_j = \widetilde{T}_i$, we have $\Pi_j'(\widetilde{T}_j) = -e^{-r\widetilde{T}_i}[\Delta\pi_j - \{rK(\widetilde{T}_i) - K'(\widetilde{T}_i)\}] = -e^{-r\widetilde{T}_i}[\Delta\pi_j - \Delta\pi_i]$. Therefore, if $\Delta\pi_i > \Delta\pi_j$ holds, we have $\Pi_j'(\widetilde{T}_j) > 0$. Since $\Pi_j''(T_j) < 0$ holds by the second-order condition, the optimal timing of TA for the second adopter, which makes $\Pi_j'(\widetilde{T}_j) = 0$, satisfies $\widetilde{T}_i > \widetilde{T}_j$. If $\Delta\pi_i \leq \Delta\pi_j$ holds, we have $\Pi_j'(\widetilde{T}_j) < 0$, meaning that the second adopter has no incentive to delay the timing of TA once the first adopter implements TA. In this case, firms anticipate that $T_i = T_j$ hold and $\Pi_i(T_i)$ and $\Pi_j(T_j)$ become $\Pi_i(T_i) = \int_0^{T_i} e^{-rt}\overline{\pi}_i(\overline{c})\,dt + \int_{T_i}^{\infty} e^{-rt}\underline{\pi}_i(\underline{c})\,dt - e^{-rT_i}K(T_i)$ and $\Pi_j(T_j) = \int_0^{T_j} e^{-rt}\overline{\pi}_j(\overline{c})\,dt + \int_{T_j}^{\infty} e^{-rt}\underline{\pi}_j(\underline{c})\,dt - e^{-rT_j}K(T_j)$. Then, $\Pi_i'(\widetilde{T}_i) = \Pi_j'(\widetilde{T}_j) = 0$ holds at $\widetilde{T}_i = \widetilde{T}_j$ if and only if $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) = \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ is satisfied. If

$\Delta\pi_i \leq \Delta\pi_j$ and $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) \neq \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ hold, a firm always has an incentive to deviate from $T_i = T_j$ in determining the timing of TA. This contradicts the supposition that $T_i = T_j$ holds and $\widetilde{T}_i = \widetilde{T}_j$ cannot be an equilibrium outcome. ■

A.5 Proof of Lemma 1

Given $\tau_X = \tau_Y = \tau > 0$ and for $h \in \{X, Y\}$, we have (i) $\overline{\Omega}_h(\overline{c}, E) - \overline{\Omega}_h(\overline{c}, I) = \overline{\Omega}_h(\underline{c}, E) - \overline{\Omega}_h(\underline{c}, I) = \underline{\Omega}_h(\overline{c}, E) - \underline{\Omega}_h(\overline{c}, I) = \underline{\Omega}_h(\underline{c}, E) - \underline{\Omega}_h(\underline{c}, I) = 4\tau^2/9b > 0$, and (ii) $\underline{\Omega}_h(\overline{c}, E) - \underline{\Omega}_h(\underline{c}, E) = \underline{\Omega}_h(\underline{c}, E) - \overline{\Omega}_h(\overline{c}, E) = \overline{\Omega}_h(\overline{c}, E) - \overline{\Omega}_h(\underline{c}, E) = \underline{\Omega}_h(\overline{c}, I) - \underline{\Omega}_h(\underline{c}, I) = \underline{\Omega}_h(\underline{c}, I) - \overline{\Omega}_h(\overline{c}, I) = \overline{\Omega}_h(\overline{c}, I) - \overline{\Omega}_h(\underline{c}, I) = 4(\overline{c} - \underline{c})\tau/9b > 0$. ■

A.6 The marginal gains from TA in multilateral liberalization

In Region I, $\underline{F}(\overline{c}, E) \leq F$ holds such that firms always prefer exporting. In this case, irrespective of firms' technology adoption (i.e., in all three phases), the equilibrium outcome always becomes (E, E). Given $T_i < T_j$, the marginal gains from TA become

$$\Delta\pi_i^M(I) = \pi_i(\underline{c}, \tau; \overline{c}, \tau) - \pi_i(\overline{c}, \tau; \overline{c}, \tau), \tag{12}$$

$$\Delta\pi_j^M(I) = \pi_j(\underline{c}, \tau; \underline{c}, \tau) - \pi_j(\overline{c}, \tau; \underline{c}, \tau). \tag{13}$$

Because $\Delta\pi_i^M(I) > \Delta\pi_j^M(I)$ always holds, we have $\widetilde{T}_i^M(I) < \widetilde{T}_j^M(I)$ as the unique equilibrium timings of TA in this region. Even though both firms always choose the same location strategy, the equilibrium timing of TA differ between the firms. This is because TA by one firm reduces the gains from TA by the other firm. In other words, the two firms' decisions on TA are strategic substitutes. Since $\partial\{\Delta\pi_i^M(I)\}/(\partial\tau) = \partial\{\Delta\pi_j^M(I)\}/(\partial\tau) = -4(\overline{c} - \underline{c})/(9b) < 0$, these gains decrease with trade costs.

In Region II, where $\underline{F}(\underline{c}, E) \leq F < \underline{F}(\overline{c}, E)$ holds, both firms choose exporting and the equilibrium outcome becomes (E, E) in Phase 1. In Phase 2, the first adopter who reduces the production cost chooses FDI, and the equilibrium location becomes (I, E). Therefore, the first adopter's gains now become

$$\Delta\pi_i^M(II) = \{\pi_i(\underline{c}, 0; \overline{c}, \tau) - F\} - \pi_i(\overline{c}, \tau; \overline{c}, \tau), \tag{14}$$

where $\Delta\pi_i^M(I) = \Delta\pi_i^M(II)$ at $F = \underline{F}(\overline{c}, E)$ and increase as F declines. However, in Phase 3, the first adopter's FDI becomes unprofitable because the first adopter no longer enjoys a technological advantage over the second adopter. The second adopter still does not undertake FDI in this case. Therefore, the equilibrium locations return to $(E.E)$. The second adopter's marginal gains from TA become

$$\Delta\pi_j^M(II) = \pi_j(\underline{c}, \tau; \underline{c}, \tau) - \pi_j(\overline{c}, \tau; \underline{c}, 0). \tag{15}$$

The second adopter's gains jump up from those in Region 1, $\Delta\pi_j^M(II) > \Delta\pi_j^M(I)$, because its TA not only decrease the marginal cost but also changes the first adopter's supply mode from FDI to exporting.

Here, the ranking between $\Delta\pi_i^M(II)$ and $\Delta\pi_j^M(II)$ is ambiguous: $\Delta\pi_i^M(II) \le \Delta\pi_j^M(II)$ holds if the technology gap, $\overline{c} - \underline{c}$, is not very large and $\Delta\pi_i^M(II) > \Delta\pi_j^M(II)$ holds otherwise. With $\Delta\pi_i^M(II) > \Delta\pi_j^M(II)$, the two firms adopt the new technology at different times ($\widetilde{T}_i^M(II) > \widetilde{T}_j^M(II)$). In this case, both firms' timings of TA become earlier than those in Region I, because $\Delta\pi_i^M(II) > \Delta\pi_i^M(I)$ and $\Delta\pi_j^M(II) > \Delta\pi_j^M(I)$ mean that $\widetilde{T}_i^M(II) < \widetilde{T}_i^M(I)$ and $\widetilde{T}_j^M(II) < \widetilde{T}_j^M(I)$ hold. This case is depicted in the upper diagram in Figure 6.

With $\Delta\pi_i^M(II) \le \Delta\pi_j^M(II)$, however, the two firms choose the same locations in Phases 1 and 3 in this region, and $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) = \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ holds in this region. By Proposition 3, both firms adopt the new technology at the same time, $\widehat{T}^M(II)$, and the equilibrium locations remain (E, E) despite the two firms' simultaneous TA. In this case, the marginal gains of both firms are given by

$$\Delta\widehat{\pi}^M(II) = \pi_i(\underline{c}, \tau; \underline{c}, \tau) - \pi_i(\overline{c}, \tau; \overline{c}, \tau). \tag{16}$$

It is notable that $\Delta\widehat{\pi}^M(II)$ is smaller than $\Delta\pi_j^M(I)$, meaning that the move from Region I to Region II by FDI liberalization discourages both firms' TA in this case, and $\widetilde{T}_j^M(I) < \widehat{T}^M(II)$ holds. This case is depicted in the lower diagram in Figure 6, with a cut-off level of F, $\widehat{F}$, such that $\Delta\pi_i^M(II) \le \Delta\pi_j^M(II)$ holds for $\widehat{F} \le F < \underline{F}(\overline{c}, E)$ and $\Delta\pi_i^M(II) > \Delta\pi_j^M(II)$ holds for $\underline{F}(\underline{c}, E) \le F < \widehat{F}$. In the diagram, the alternate long and short dash line represents $\Delta\widehat{\pi}(II)$. $\Delta\pi_i^M(II)$ decreases with trade costs since $\partial\{\Delta\pi_i^M(II)\}/(\partial\tau) = -4(a - \underline{c})/(9b) < 0$ but the sign of $\partial\{\Delta\pi_j^M(II)\}/(\partial\tau)$ is ambiguous. We can show that $\Delta\pi_j^M(II)$ is increasing in trade cost if $a > \overline{c} + 3\{(\overline{c} - \underline{c}) + \tau\}$ holds and decreasing in trade cost otherwise. $\Delta\widehat{\pi}^M(II)$ is decreasing in τ because $\partial\{\Delta\widehat{\pi}^M(II)\}/(\partial\tau) = -2(\overline{c} - \underline{c})/(9b) < 0$ holds.

In Region III, where $\underline{F}(\underline{c}, I) \le F < \underline{F}(\underline{c}, E)$ holds, we still have (E, E) in Phase 1 and (I, E) in Phase 2 as in Region II and the first adopter's marginal gains from TA, $\Delta\pi_i^M(III)$, is also defined by (14). Since $\Delta\pi_i^M(III)$ increase as F declines $\Delta\pi_i^M(III) > \Delta\pi_i^M(II)$ holds. However, in Phase 3, both (I, E) and (E, I) is possible, meaning that either the first adopter or the second adopter undertake FDI after both firms undertake TA. Here, there is a possibility that the second adopter's TA may have an "FDI conversion effect," in that it crowds out the rival's FDI and induces its own FDI. In this case, the second adopter's marginal gains are given by

$$\Delta\pi_j^M(III) = \{\pi_j(\underline{c}, 0; \underline{c}, \tau) - F\} - \pi_j(\overline{c}, \tau; \underline{c}, 0), \tag{17}$$

where $\Delta\pi_j^M(III) = \Delta\pi_j^M(II)$ holds at $F = \underline{F}(\underline{c}, E)$ and increases as F declines. If $\Delta\pi_i^M(III) > \Delta\pi_j^M(III)$ holds as is depicted in both diagrams in Figure 6, these location pattern changes become an equilibrium outcome. If $\Delta\pi_i^M(III) \leq \Delta\pi_j^M(III)$ holds, however, Proposition 3 tells us they cannot be an equilibrium outcome since the same location choices in Phase 1 and the different location choices in Phase 3 mean that $\underline{\pi}_i(\underline{c}) - \overline{\pi}_i(\overline{c}) \neq \underline{\pi}_j(\underline{c}) - \overline{\pi}_j(\overline{c})$ holds.[14] The sign of $\partial\{\Delta\pi_j^M(III)\}/(\partial\tau)$ is ambiguous, and positive if $a > \{4\overline{c} - \underline{c}\}/3 + \tau$ holds and negative otherwise.

If firms anticipate that (I, E) becomes the equilibrium location in Phase 3, the second adopter's TA does not change the equilibrium location pattern. In this case, the marginal gains of the second adopter are given by

$$\Delta\pi_j^{M\prime}(III) = \pi_j(\underline{c}, \tau; \underline{c}, 0) - \pi_j(\overline{c}, \tau; \underline{c}, 0) \tag{18}$$

and the optimal level of its TA is denoted by $\widetilde{T}_j^{M\prime}(III)$. Because the rival firm's FDI reduces the gains from TA, $\Delta\pi_j^{M\prime}(III) < \Delta\pi_j^M(I)$ always holds. This means that, even if the fixed costs of FDI is uniformly reduced, the liberalization of FDI encourages TA by one firm and discourages TA by the other firm. In any case, $\widetilde{T}_i^M(III) < \widetilde{T}_j^M(III)$ and $\widetilde{T}_j^M(III) < \widetilde{T}_j^M(I) < \widetilde{T}_j^{M\prime}(III)$ hold. Furthermore, we can prove that $\Delta\pi_j^{M\prime}(III) > \Delta\widehat{\pi}(II)$ holds as long as $\tau < \overline{c} - \underline{c}$, meaning that $\widetilde{T}_j^{M\prime}(III) < \widehat{T}^M(II)$ holds. Even though the second adopter's timing of TA is delayed in comparison to the timing of TA in Region I, it is still earlier than the timing of TA in Region II when both firms adopt the new timing simultaneously. We have $\partial\{\Delta\pi_j^{M\prime}(III)\}/(\partial\tau) = -8(\overline{c} - \underline{c})/(9b) < 0$.

In Region IV, where $\overline{F}(\overline{c}, E) \leq F < \underline{F}(\underline{c}, I)$ holds, the equilibrium locations in Phase 1 and Phase 2 are still the same as those in Region II and Region III. Therefore, $\Delta\pi_i^M(IV)$ is defined by (14) and $\Delta\pi_i^M(IV) > \Delta\pi_i^M(III)$ always hold. In this region, however, the second adopter undertakes FDI for its TA without crowding out the first adopter's FDI, already made in Phase 2. Hence, Firm j's TA changes the equilibrium locations from (I, E) to (I, I). Therefore, its gains from TA become

$$\Delta\pi_j^M(IV) = \{\pi_j(\underline{c}, 0; \underline{c}, 0) - F\} - \pi_i(\overline{c}, \tau; \underline{c}, 0), \tag{19}$$

where $\Delta\pi_j^M(IV) = \Delta\pi_j^{M\prime}(III)$ hold at $F = \underline{F}(\overline{c}, E)$ and it increases as F declines. Since $\Delta\pi_i^M(IV) >$

[14] If $\overline{c} - \underline{c}$ is large enough such that $\Delta\pi_i^M(III) \leq \Delta\pi_j^M(III)$ holds, the Firm i does not anticipate a Phase 2 when it adopts the new technology, and its gains from technology adoption are given by $\pi_i(\underline{c}, \tau; \underline{c}, 0) - \pi_i(\overline{c}, \tau; \overline{c}, \tau)$, which is lower than the gains of Firm j $(\pi_j(\underline{c}, 0; \underline{c}, \tau) - \pi_j(\overline{c}, \tau; \overline{c}, \tau))$, which becomes the FDI firm in Phase 3. This means that firm j adopts the new technology earlier, which contradicts the supposition that Firm i is the first adopter.

$\Delta\pi_j^M(IV)$ always hold, we have $\widetilde{T}_i^M(IV) < \widetilde{T}_j^M(IV)$, $\widetilde{T}_i^M(IV) < \widetilde{T}_i^M(III)$, and $\widetilde{T}_j^M(IV) < \widetilde{T}_j^{M'}(III)$. The ranking between $\widetilde{T}_j^M(IV)$ and $\widetilde{T}_j^M(III)$ is ambiguous. Since trade costs only reduces the pre-adoption profit, $\Delta\pi_j^M(IV)$ is increasing in τ.

In Region V, where the fixed cost satisfies $\overline{F}(\bar{c}, I) \leq F < \overline{F}(\bar{c}, E)$, the equilibrium locations in Phase 2 and Phase 3 are the same in Region IV. Therefore, $\Delta\pi_j^M(IV)$ is given by (19) and it increases as F decreases. Therefore, $\Delta\pi_j^M(V) > \Delta\pi_j^M(IV)$ always holds. However, at this level of fixed cost, an FDI by one of two firms becomes profitable even before the first adopter's TA in this region. Therefore, the equilibrium locations become either (I, E) or (E, I) in Phase 1. This implies that TA by the first adopter may also cause an FDI conversion effect in favor of the first adopter, because it may change the location patterns from (E, I) to (I, E).

If FDI conversion from Phase 1 to Phase 2 occurs, the first adopter's marginal gains from TA become

$$\Delta\pi_i^M(V) = \{\pi_i(\underline{c}, 0; \bar{c}, \tau) - F\} - \pi_i(\bar{c}, \tau; \bar{c}, 0). \tag{20}$$

Because Firm i's TA has an extra effect that changes the equilibrium locations in favor of itself, the gains from TA jumps up from the levels in Region IV, and $\Delta\pi_i^M(V) > \Delta\pi_i^M(IV)$ holds. As F decreases, $\Delta\pi_i^M(V)$ increases. If no FDI conversion occurs from Phase 1 to Phase 2, the first adopter undertakes FDI in both phases and its marginal gains from TA are given by

$$\Delta\pi_i^{M'}(V) = \pi_i(\underline{c}, 0; \bar{c}, \tau) - \pi_i(\bar{c}, 0; \bar{c}, \tau), \tag{21}$$

where $\Delta\pi_i^{M'}(V) = \Delta\pi_i^M(IV)\big|_{F=\overline{F}(\bar{c},E)}$ holds. Since we have $\Delta\pi_i^{M'}(V) > \Delta\pi_j^M(V)$ and $\Delta\pi_i^{M'}(V) \geq \Delta\pi_i^M(IV)$ with equality if $F = \overline{F}(\bar{c}, E)$, the equilibrium timings of TA satisfy $\widetilde{T}_i^M(V) < \widetilde{T}_j^M(V)$ and $\widetilde{T}_i^M(V) < \widetilde{T}_i^{M\prime}(V) \leq \widetilde{T}_i^M(IV)$. $\Delta\pi_i^M(V)$ is increasing in τ if $a > \{\bar{c} + 2\underline{c}\}/3 + \tau$ holds and decreasing in τ otherwise. $\Delta\pi_i^{M'}(V)$ is increasing in τ since $\partial\{\Delta\pi_i^{M'}(V)\}/(\partial\tau) = 4(\bar{c} - \underline{c})/(9b) > 0$ holds.

In Region VI, where $\overline{F}(\underline{c}, I) \leq F < \overline{F}(\bar{c}, I)$ holds, the equilibrium properties in Phase 2 and Phase 3 remain unchanged, meaning that $\Delta\pi_j^M(VI)$ is defined by (19) and $\Delta\pi_j^M(VI) \geq \Delta\pi_j^M(V)$ holds with equality at $F = \overline{F}(\bar{c}, I)$. At this level of fixed cost, however, it is low enough to induce both firms to undertake FDI in Phase 1, and the equilibrium location becomes (I, I). Then, after the first adopter's TA, there emerges a technology gap between the two firms ,and the inefficient firm's FDI (i.e., the second adopter's FDI) is kicked out in Phase 2. This implies that the first adopter's TA generates not only a cost-advantage but also a location advantage over the rival firm in Phase 2. The first adopter's marginal gains from TA become

$$\Delta\pi_i(VI) = \pi_i(\underline{c}, 0; \bar{c}, \tau) - \pi_i(\bar{c}, 0; \bar{c}, 0), \tag{22}$$

where $\Delta\pi_i^M(VI) = \Delta\pi_i^M(V)\big|_{F=\overline{F}(\bar{c},I)} > \Delta\pi_j^M(VI)$ holds. Therefore, $\widetilde{T}_i^M(VI) \leq \widetilde{T}_i^M(V) < \widetilde{T}_j^M(VI) < \widetilde{T}_j^M(V)$ holds. Since an increase in trade cost only increases the post-adoption profit, $\Delta\pi_i(VI)$ is increasing in τ.

Finally, in Region VII, where $0 \leq F < \overline{F}(\underline{c}, I)$ holds, both firms always undertake FDI irrespective of their TA. Hence, the marginal gains from TA become

$$\Delta\pi_i^M(VII) = \pi_i(\underline{c}, 0; \bar{c}, 0) - \pi_i(\bar{c}, 0; \bar{c}, 0), \quad (23)$$

$$\Delta\pi_j^M(VII) = \pi_j(\underline{c}, 0; \underline{c}, 0) - \pi_j(\bar{c}, 0; \underline{c}, 0). \quad (24)$$

Now, the first adopter's TA does not have a strategic effect that kicks out the rival's FDI, so $\Delta\pi_i^M(VII) < \Delta\pi_i^M(VI)$ holds. Since $\Delta\pi_i^M(VII) > \Delta\pi_j^M(VII) = \Delta\pi_j^M(VI)\big|_{F=\overline{F}(\underline{c},I)}$ always holds, we have $\widetilde{T}_i^M(VI) < \widetilde{T}_i^M(VII) < \widetilde{T}_j^M(VII) \leq \widetilde{T}_j^M(VI)$. Apparently, $\Delta\pi_i^M(VII)$ and $\Delta\pi_j^M(VII)$ are independent of trade costs.

A.7 Proof of Lemma 2

By Appendix A.6, $\Delta\pi_i^M(II) - \Delta\pi_j^M(II) = [3\tau^2 + 2\{a - \bar{c} + 5(\bar{c} - \underline{c})\}\tau + 4\,(\bar{c} - \underline{c})^2]/(9b) - F$. In Region II, $\underline{F}(\underline{c}, E) \leq F < \underline{F}(\bar{c}, E)$ holds. We have $\Delta\pi_i^M(II) - \Delta\pi_j^M(II)\big|_{F=\underline{F}(\bar{c},E)} = -[2\{(a - \bar{c}) - (\bar{c} - \underline{c})\}\tau - 4\,(\bar{c} - \underline{c})^2 - 3\tau^2]/(9b)$, and it is negative if a is large enough and $(\bar{c} - \underline{c})^2$ is small enough, meaning that $\Delta\pi_i^M(II) \leq \Delta\pi_j^M(II)$ holds at least within some range in Region II. In this case, both firms undertake TA at the same time and their gains become $\Delta\widehat{\pi}^M(II)$. By comparing $\Delta\widehat{\pi}^M(II)$ with $\Delta\pi_j^{M\prime}(III)$, we have $\Delta\widehat{\pi}^M(II) - \Delta\pi_j^{M\prime}(III) = \pi_i(\underline{c}, \tau; \underline{c}, \tau) - \pi_j(\underline{c}, \tau; \underline{c}, 0) + \pi_j(\bar{c}, \tau; \underline{c}, 0) - \pi_i(\bar{c}, \tau; \bar{c}, \tau) < 0$, because $\pi_i(\underline{c}, \tau; \underline{c}, \tau) < \pi_j(\underline{c}, \tau; \underline{c}, 0)$ and $\pi_j(\bar{c}, \tau; \underline{c}, 0) < \pi_i(\bar{c}, \tau; \bar{c}, \tau)$ always hold. Because $\Delta\pi_j^{M\prime}(III)$ is the lowest level among all possible gains from TA when firms choose the different timing of TA, multilateral liberalization of FDI that changes the location equilibrium from Region I to Region II delays TA for both firms. ■

A.8 Proof of Proposition 4

By Appendix A.6, $\widetilde{T}_i^M(VI)$ is the earliest timing of TA for the first adopter. With regard to the second adopter, Appendix A.6 proves that $\widetilde{T}_i^M(VI) \leq \widetilde{T}_j^M(VI)$, and $\widetilde{T}_j^M(VI)$ is earlier than $\widetilde{T}_j^M(V)$ and $\widetilde{T}_j^M(IV)$. Because $\Delta\pi_j^M(VII) - \Delta\pi_j^M(I) = 4(\bar{c} - \underline{c})\tau/(9b) > 0$, $\widetilde{T}_j^M(VII) < \widetilde{T}_j^M(I)$ holds. (i) Suppose that TA by the second adopter causes an FDI conversion effect. Since $\Delta\pi_j^M(III) \geq \Delta\pi_j^M(II)$, and $\Delta\pi_j^M(III)$ is decreasing in F, $\Delta\pi_j^M(III)$ takes the highest level at $F = \underline{F}(\underline{c}, I)$ in Region III. We have $\Delta\pi_j^M(III)\big|_{F=\underline{F}(\underline{c},I)} - \Delta\pi_j^M(VII) = \{2(a - \bar{c}) - 6(\bar{c} - \underline{c}) + \tau\}\tau/(9b)$, so $\Delta\pi_j^M(III)\big|_{F=\underline{F}(\underline{c},I)} > \Delta\pi_j^M(VII)$

holds if $a > \bar{c} + 3\{(\bar{c} - \underline{c}) - \tau/2$ holds. In this case, $\widetilde{T}_j^M(III)$ at $F = \underline{F}(\underline{c}, I)$ is the earliest timing of TA by the second adopter. (ii) Suppose that TA by the second adopter does not cause an FDI conversion effect. In this case, we have $\Delta\pi_j^{M'}(III)$ in Region III, and $\widetilde{T}_j^M(VII) < \widetilde{T}_j^{M\prime}(III)$ holds. We have $\Delta\pi_j^M(II) - \Delta\pi_j^M(VII) = \{2(a - \bar{c}) - 6(\bar{c} - \underline{c}) - 3\tau\}\tau/(9b)$, so $\Delta\pi_j^M(II) > \Delta\pi_j^M(VII)$ holds if $a > \bar{c} + 3\{(\bar{c} - \underline{c}) + \tau/2\}$ holds. In this case, $\widetilde{T}_j^M(II)$ is the earliest timing of TA by the second adopter. (iii) Otherwise, $\widetilde{T}_j^M(VII)$ is the earliest timing of TA. ■

A.9 Proof of Proposition 5

As in the multilateral liberalization of FDI, the earliest timing of TA for the first adopter is realized in Region VI, where $\overline{\tau}(\bar{c}, I) < \tau \leq \underline{\tau}(\bar{c}, E)$ holds. Since $\Delta\pi_i(VI)$ increases as τ increases, it takes the maximum level at $\tau = \underline{\tau}(\bar{c}, E)$. With regard to the second adopter, its gains from TA in Region I with $\tau = 0$ and those in Region VII coincide, and they are larger than the gains from TA in Regions IV, V, and VI. (i) Suppose that TA by the second adopter has an FDI conversion effect in Region III, where $\underline{\tau}(\underline{c}, E) < \tau \leq \underline{\tau}(\underline{c}, I)$ holds. Given that $\Delta\pi_j(III)$ is either increasing or decreasing in τ, there is the unique level of τ, $\tau^*(III)$, in $\tau \in [\underline{\tau}(\underline{c}, E) + \varepsilon, \underline{\tau}(\underline{c}, I)]$ such that $\Delta\pi_j(III)$ takes the maximum level within the region, where ε is the infinitesimal value. If $a > \bar{c} + 3(\bar{c} - \underline{c}) - \tau^*(III)/2$ holds, the gains from TA by the second adopter in Region III are higher than those at $\tau = 0$ and in Region VII. Similarly, $\Delta\pi_j(II)$ is either increasing or decreasing in τ, where $\underline{\tau}(\bar{c}, E) < \tau \leq \underline{\tau}(\underline{c}, E)$ holds. There is the unique level of τ, $\tau^*(II)$, in $\tau \in [\underline{\tau}(\bar{c}, E) + \varepsilon, \underline{\tau}(\underline{c}, E)]$ at which $\Delta\pi_j(II)$ takes the highest level within the region. If $a > \bar{c} + 3\{(\bar{c} - \underline{c}) + \tau^*(II)/2\}$ holds, the gains from TA by the second adopter in Region II are higher than those at $\tau = 0$ and in Region VII. If both inequality holds, which region attains the quickest TA by the second adopter depends on the ranking between $\Delta\pi_j(II)|_{\tau=\tau^*(II)}$ and $\Delta\pi_j(III)|_{\tau=\tau^*(III)}$. In either case, a tariff in $\tau \in (\underline{\tau}(\bar{c}, E), \underline{\tau}(\underline{c}, I)]$ realizes the maximum level of $\Delta\pi_j$. ■

A.10 The cut-off levels of the fixed cost under preferential liberalization

Given $F_X = F_Y = F^0 > \underline{F}(\bar{c}, E)$ and $\tau_X = \tau_Y = \tau^0$, Firm Y always chooses exporting in every situation. By Lemma 1, the cut-off levels of Firm X's FDI, given $s_Y = E$, are $\underline{\Omega}_X(\bar{c}, E) > \underline{\Omega}_X(\underline{c}, E) > \overline{\Omega}_X(\bar{c}, E) > \overline{\Omega}_X(\underline{c}, E)$. Among them, $\underline{\Omega}_X(\bar{c}, E)$, $\underline{\Omega}_X(\underline{c}, E)$, and $\overline{\Omega}_X(\bar{c}, E)$ respectively coincide with $\underline{\Omega}_i(\bar{c}, E)$, $\underline{\Omega}_h(\underline{c}, E)$, and $\overline{\Omega}_h(\bar{c}, E)$ in multilateral liberalization. Hence, Region i and Region ii of preferential liberalization respectively coincide with Region I and Region II of multilateral liberalization, and Region iii corresponds to Regions III and IV combined. By Lemma 1, $\overline{\Omega}_X(\underline{c}, E) - \overline{\Omega}_h(\bar{c}, I) = 4\tau\{\tau - (\bar{c} - \underline{c})\}/9b$, $\overline{\Omega}_X(\underline{c}, E) < \overline{\Omega}_h(\bar{c}, I)$ holds as long as $\tau < \bar{c} - \underline{c}$ and $\overline{\Omega}_X(\underline{c}, I) < \overline{\Omega}_X(\underline{c}, E)$ hold. Therefore, Region iv corresponds to Region V and a part of Region VI, while Region v corresponds to a part of Region VI and the whole range in Region VII.

A.11 Proof of Proposition 6

The location changes induced by the first adopter's TA in Region i, ii and iii are the same as those in multilateral liberalization, meaning that the first adopter implements TA at the same time. In Regions vi and v, Firm X always undertakes FDI in Phases 1 and 2, and the gains from TA coincide with $\Delta\pi_i^{M'}(V)$. Since multilateral liberalization can realize higher gains from TA in $F \in [\overline{F}(\underline{c}, I), \overline{F}_X(\underline{c}, E))$, because of the FDI blocking effect of TA, it attains TA earlier than preferential liberalization does in this range of the fixed cost. In $F \in [0, \overline{F}(\underline{c}, I))$, however, preferential liberalization attains TA earlier, because $\Delta\pi_i^M(VII) < \Delta\pi_i^{M'}(V)$ holds in this range. With regards to Firm Y's TA, the location changes and the timing of TA are indifferent between preferential liberalization and multilateral liberalization. In Regions iii, iv, and v, the Firm Y's gains from TA coincide with $\Delta\pi_j^{M\prime}(III)$. Because $\Delta\pi_j^{M\prime}(III)$ is the lowest possible level of TA by the second adopter in multilateral liberalization, multilateral liberalization attains TA weakly earlier than preferential liberalization does. ■

A.12 Proof of Proposition 7

In Regions i to iii, TA by the first adopter does not changes the equilibrium locations and both firms choose exporting in Phases 1 and 2. The gains from TA for the first adopter become the same as $\Delta\pi_i^M(I)$. In Regions ii and iii, the gains from TA in preferential liberalization are lower than those in multilateral liberalization, because the first adopter's TA induces its own FDI in the latter case. In Region iv, the second adopter undertakes FDI in Phase 1 and the first adopter's TA blocks the second adopter's TA and changes the equilibrium locations from (E, I) to (E, E). Because of this extra effect of TA, the first adopter's gains from TA jumps up from $\Delta\pi_i^M(I)$ to $\Delta\pi_Y^P(vi) = \pi_Y(\underline{c}, \tau; \overline{c}, \tau) - \pi_Y(\overline{c}, \tau; \overline{c}, 0)$. $\Delta\pi_Y^P(vi) - \Delta\pi_i^{M\prime}(V) = \{2(a-\overline{c}) - 8(\overline{c}-\underline{c}) - 3\tau\}\tau/(9b)$, $\Delta\pi_Y^P(vi) > \Delta\pi_i^{M\prime}(V)$ holds if $a > \overline{c} + 4(\overline{c}-\underline{c}) + 3\tau/2$ holds, and $\Delta\pi_Y^P(vi) \leq \Delta\pi_i^{M\prime}(V)$ holds otherwise. We also have $\Delta\pi_Y^P(vi) - \Delta\pi_i^M(V)\big|_{F=\overline{F}_X(\overline{c},E)} = -8(\overline{c}-\underline{c})\tau/(9b) < 0$, meaning that the first adopter's TA is always earlier in multilateral liberalization if it causes the FDI conversion effect, it can be earlier in preferential liberalization if it does not. In Region v, the second adopter always chooses FDI, which diminishes the first adopter's gains from TA to $\Delta\pi_Y^P(v) = \pi_Y(\underline{c}, \tau; \overline{c}, 0) - \pi_Y(\overline{c}, \tau; \overline{c}, 0)$. The corresponding marginal gains in this region in multilateral liberalization are $\Delta\pi_i^M(VI)$ and $\Delta\pi_i^M(VII)$. Since $\Delta\pi_Y^P(v) - \Delta\pi_i^M(VII) = -8(\overline{c}-\underline{c})\tau/(9b) < 0$ and $\Delta\pi_i^M(VI) > \Delta\pi_i^M(VII)$, TA in this region occurs later than the timing of TA in multilateral liberalization. Therefore, $\Delta\pi_Y^P$ is no higher than $\Delta\pi_i^M$ in all regions.

With regard to the second adopter (Firm X), its gains from TA in Regiond i and ii become the same as $\Delta\pi_j^M(I)$. In Region ii, because of the absence of the FDI blocking effect, TA in preferential liberalization occurs later than that in multilateral liberalization. In Regions iii to iv, the gains from TA are given by $\Delta\pi_X^P(iii) = \Delta\pi_X^P(iv) = \{\pi_X(\underline{c}, 0; \underline{c}, \tau) - F\} - \pi_X(\bar{c}, \tau; \underline{c}, \tau)$, which are the same as $\Delta\pi_j^M(I)$ at $F = \underline{F}_X(\underline{c}, E)$ and increase as F becomes smaller. We have $\Delta\pi_X^P(iii) - \Delta\pi_j^M(III) = \pi_j(\bar{c}, \tau; \underline{c}, 0) - \pi_X(\bar{c}, \tau; \underline{c}, \tau) < 0$ and $\Delta\pi_X^P(iii) - \Delta\pi_j^{M'}(III) > \Delta\pi_X^P(iii)\big|_{F=\underline{F}_X(\underline{c},E)} - \Delta\pi_j^{M'}(III) = \Delta\pi_j^M(I) - \Delta\pi_j^{M'}(III) > 0$. Hence, in Region iii, preferential liberalization can either attain an earlier timing of TA or a later timing of TA than multilateral liberalization does for $F \in [\underline{F}(\underline{c}, I), \underline{F}_X(\underline{c}, E))$. For $F \in [\overline{F}_X(\bar{c}, E), \underline{F}(\underline{c}, I))$ in Region iii, the corresponding gains from TA in multilateral liberalization are $\Delta\pi_j^M(IV)$. Since both $\Delta\pi_X^P(iii)$ and $\Delta\pi_j^M(IV)$ are decreasing in F and $\Delta\pi_X^P(iii) - \Delta\pi_j^{M'}(III) > 0$ holds, $\Delta\pi_X^P(iii) > \Delta\pi_j^M(IV)$ is always satisfied. By the same reason, $\Delta\pi_X^P(iv)$ is higher than the corresponding gains in multilateral liberalization. In Region v, we have $\Delta\pi_X^P(v) = \pi_X(\underline{c}, 0; \underline{c}, \tau) - \pi_X(\bar{c}, 0; \underline{c}, \tau)$ and $\Delta\pi_X^P(v) - \Delta\pi_j^M(VII) = 4(\bar{c} - \underline{c})\tau/(9b) > 0$.

In Region iv and v, $\Delta\pi_X^P$ can be higher than $\Delta\pi_Y^P$. For instance, we have $\Delta\pi_X^P(v) - \Delta\pi_Y^P(v) = 4(\bar{c} - \underline{c})\{3\tau - (\bar{c} - \underline{c})\}/(9b)$, which is positive if $\tau > (\bar{c} - \underline{c})/3$ holds. Similarly, we can verify that $\Delta\pi_X^P > \Delta\pi_Y^P$ may hold at some point in Region iv if $4(\bar{c} - \underline{c})(2\tau - (\bar{c} - \underline{c})) - 2(a - c_H)\tau + 3\tau^2 > 0$ holds. In Region iii, however, $\Delta\pi_X^P(iii) - \Delta\pi_Y^P(iii) < \Delta\pi_X^P(iii) - \Delta\pi_Y^P(iii)\big|_{F=\overline{F}_X(\underline{c},E)} = 4(\bar{c} - \underline{c})\{\tau - (\bar{c} - \underline{c})\}/(9b) < 0$ holds as long as $\tau < (\bar{c} - \underline{c})$ holds, which we assume throughout the paper. If $\Delta\pi_X^P > \Delta\pi_Y^P$, by Proposition 3, firm X cannot be the second adopter in equilibrium and it always becomes the first adopter wherever $\Delta\pi_X^P > \Delta\pi_Y^P$ holds. ■

A.13 Proof of Proposition 9

The discounted sum of consumer surplus in the domestic country is defined as

$$S(T_i, T_j) = \int_0^{T_i} e^{-rt} CS(\bar{c}, \tau_i; \bar{c}, \tau_j) dt + \int_{T_i}^{T_j} e^{-rt} CS(\underline{c}, \tau_i; \bar{c}, \tau_j) dt + \int_{T_j}^{\infty} e^{-rt} CS(\underline{c}, \tau_i; \underline{c}, \tau_j) dt.$$

Given that $\widetilde{T}_i^M(VI) < \widetilde{T}_i^M(VII) < \widetilde{T}_j^M(VI) = \widetilde{T}_j^M(VI)$ holds in equilibrium with $a > \bar{c} + 3(\bar{c} - \underline{c}) - \tau/2$, if we compare the discounted sum of consumer surplus in Region VI, given by $S^M(VI) = S(\widetilde{T}_i^M(VI), \widetilde{T}_j^M(VI))$, with that in Region VII, $S^M(VII) = S(\widetilde{T}_i^M(VII), \widetilde{T}_j^M(VII))$, we have

$$\begin{aligned} S^M(VI) - S^M(VII) &= \int_{\widetilde{T}_i^M(VI)}^{\widetilde{T}_i^M(VII)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\bar{c}, 0; \bar{c}, 0)]dt \\ &\quad + \int_{\widetilde{T}_i^M(VII)}^{\widetilde{T}_j^M(VI)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\underline{c}, 0; \bar{c}, 0)]dt. \end{aligned}$$

The first term of this equation is positive because $\tau < (\bar{c} - \underline{c})$ implies that $CS(\underline{c}, 0; \bar{c}, \tau) > CS(\bar{c}, 0; \bar{c}, 0)$ holds, that is, a firm's TA improves consumer surplus more than a firm's FDI does. The second term, however, is negative because the second adopter undertakes FDI in Region VII. If the gaps between $\widetilde{T}_i^M(VI)$ and $\widetilde{T}_i^M(VII)$ and between $CS(\underline{c}, 0; \bar{c}, \tau)$ and $CS(\bar{c}, 0; \bar{c}, 0)$ are large and the gaps between $\widetilde{T}_i^M(VII)$ and $\widetilde{T}_j^M(VI)$ and the gap between $CS(\underline{c}, 0; \bar{c}, 0)$ and $CS(\underline{c}, 0; \bar{c}, \tau)$ are small, $S^M(VI) > S^M(VII)$ holds. This implies that there is a case where a multilateral reduction of F that changes the equilibrium location patterns from Region VI to Region VII hurts the domestic consumers. ■

A.14 Proof of Proposition 10

Suppose that preferential liberalization of FDI targets the first adopter. If consumer surplus is maximized at $F = \overline{F}(\underline{c}, I)$ (Region VI in Figure 6), the preferential liberalization always delays the time of TA compared with the time of TA in multilateral liberalization. Since multilateral liberalization promotes FDI more than preferential liberalization does, the domestic consumers always prefer multilateral liberalization in this case. If consumer surplus is maximized at $F < \overline{F}(\underline{c}, I)$ (Region VII), preferential liberalization attains an earlier timing of TA for the first adopter if $F_X \leq \overline{F}_X(\bar{c}, E)$ (Regions iv and v in Figure 9) holds. By comparing the equilibrium times of TA, we have $\widetilde{T}_X^P(iv) = \widetilde{T}_X^P(v) < \widetilde{T}_i^M(VII) < \widetilde{T}_j^M(VII) < \widetilde{T}_Y^P(iv) = \widetilde{T}_Y^P(v)$. By comparing the discounted sum of consumer surplus between in Region iv in the case of preferential liberalization, $S^P(iv)$, and that in Region VII of multilateral liberalization, we have $S^P(iv) - S^M(VII) = \int_0^{\widetilde{T}_X^P(iv)} e^{-rt}[CS(\bar{c}, 0; \bar{c}, \tau) - CS(\bar{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_X^P(iv)}^{\widetilde{T}_i^M(VII)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\bar{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_i^M(VII)}^{\widetilde{T}_j^M(VII)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\underline{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_j^M(VII)}^{\widetilde{T}_Y^P(iv)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\underline{c}, 0; \underline{c}, 0)]dt + \int_{\widetilde{T}_Y^P(iv)}^{\infty} e^{-rt}[CS(\underline{c}, 0; \underline{c}, \tau) - CS(\underline{c}, 0; \underline{c}, 0)]dt$. Only the second term is positive and the other terms are negative. The domestic consumers prefer preferential liberalization if and only if the discounted sum of consumer gains, $CS(\underline{c}, 0; \bar{c}, \tau) - CS(\bar{c}, 0; \bar{c}, 0)$, that are obtained for $T \in [\widetilde{T}_X^P(v), \widetilde{T}_i^M(VII))$ are large enough to dominate the discounted sum of consumer losses in other periods.

Alternatively, suppose that preferential liberalization of FDI targets the second adopter. In the preferential liberalization, the discounted sum of consumer surplus is maximized for $F_X \leq \overline{F}_X(\bar{c}, E)$ (Region v) as long as $\Delta\pi_X^P < \Delta\pi_Y^P$ holds in this region, which is given by, $S^P(v)$. Let us consider the case where the highest discounted sum of consumer surplus is attained at $F = \overline{F}(\underline{c}, I)$ (Region VI), which is given by $S^M(VI)$. The equilibrium timings of TA satisfy $\widetilde{T}_i^M(VI) < \widetilde{T}_Y^P(v) < \widetilde{T}_X^P(v) < \widetilde{T}_j^M(VI)$. Then, we have $S^P(v) - S^M(VI) = \int_0^{\widetilde{T}_i^M(VI))} e^{-rt}[CS(\bar{c}, 0; \bar{c}, \tau) - CS((\bar{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_i^M(VI)}^{\widetilde{T}_Y^P(v)} e^{-rt}[CS(\bar{c}, 0; \bar{c}, \tau) - CS(\underline{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_Y^P(v)}^{\widetilde{T}_X^P(v)} e^{-rt}[CS(\underline{c}, 0; \bar{c}, \tau) - CS(\underline{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_X^P(v)}^{\widetilde{T}_j^M(VI)} e^{-rt}[CS(\underline{c}, 0; \underline{c}, \tau) - CS(\underline{c}, 0; \bar{c}, 0)]dt + \int_{\widetilde{T}_j^M(VI)}^{\infty} e^{-rt}[CS(\underline{c}, 0; \underline{c}, \tau) - CS(\underline{c}, 0; \underline{c}, 0)]dt$. The fourth term is positive while the other terms are negative. Hence, $S^P(v) > S^M(VI)$ holds and the domestic consumers prefer preferential liberalization if and only if the discounted sum of consumer gains, $CS(\underline{c}, 0; \underline{c}, \tau) - CS(\underline{c}, 0; \overline{c}, 0)$, that are obtained for $T \in [\widetilde{T}_X^P(v), \widetilde{T}_i^M(VI))$, are large enough to dominate the discounted sum of consumer losses in the other periods. Especially, if $\Delta\pi_j^M < r\underline{K} < \Delta\pi_X^P$ holds, the second adopter adopts the new technology only in the case of preferential liberalization. If that is the case, the domestic consumers' surplus is always higher from $T \geq \widetilde{T}_X^P(v)$ and we can find the cut-off level of r, below which $S^P(v) > S^M(VI)$ holds.

In sum, in a case where preferential liberalization of FDI realizes the faster timing of TA than multilateral liberalization does, the discounted sum of consumer surplus can be higher in preferential liberalization if the consumers' gains from earlier TA of the targeted firm are large enough. ■

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Figures and Tables

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

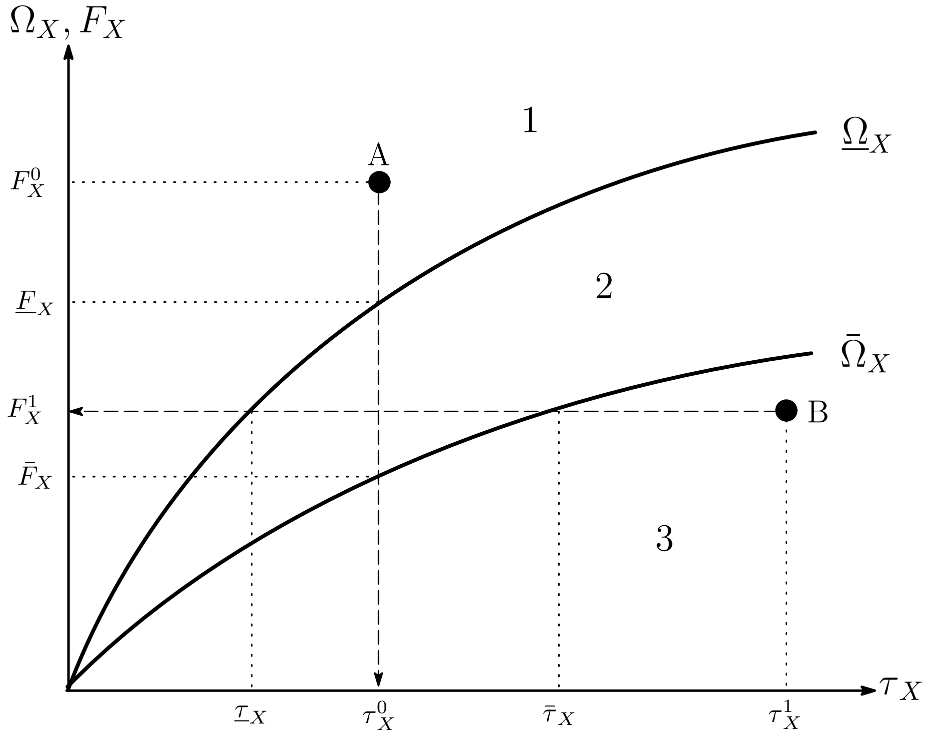


Figure 2: The Optimal Timing of Technology Adoption

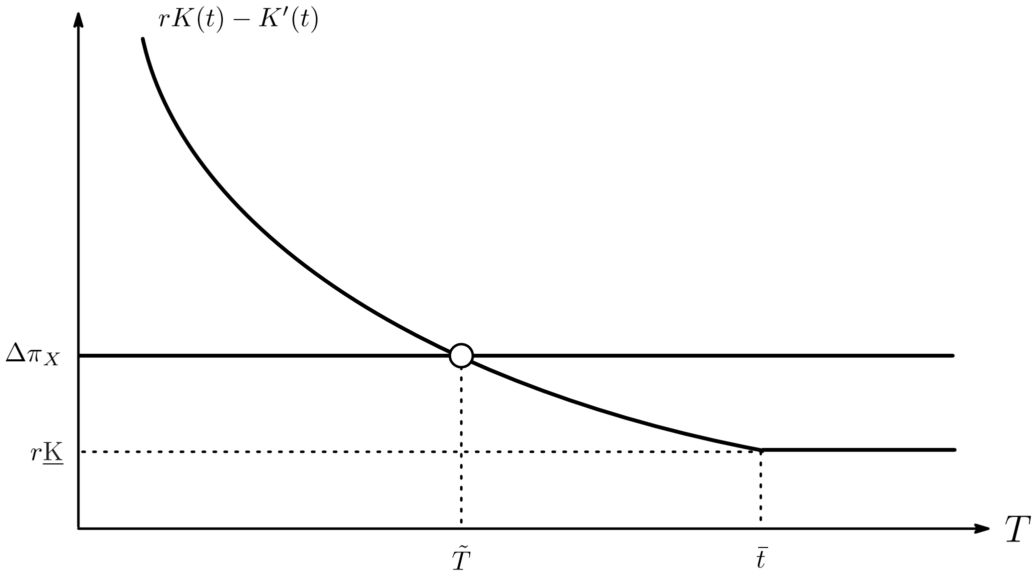


Figure 3: Liberalization of FDI (A Single Foreign Firm)

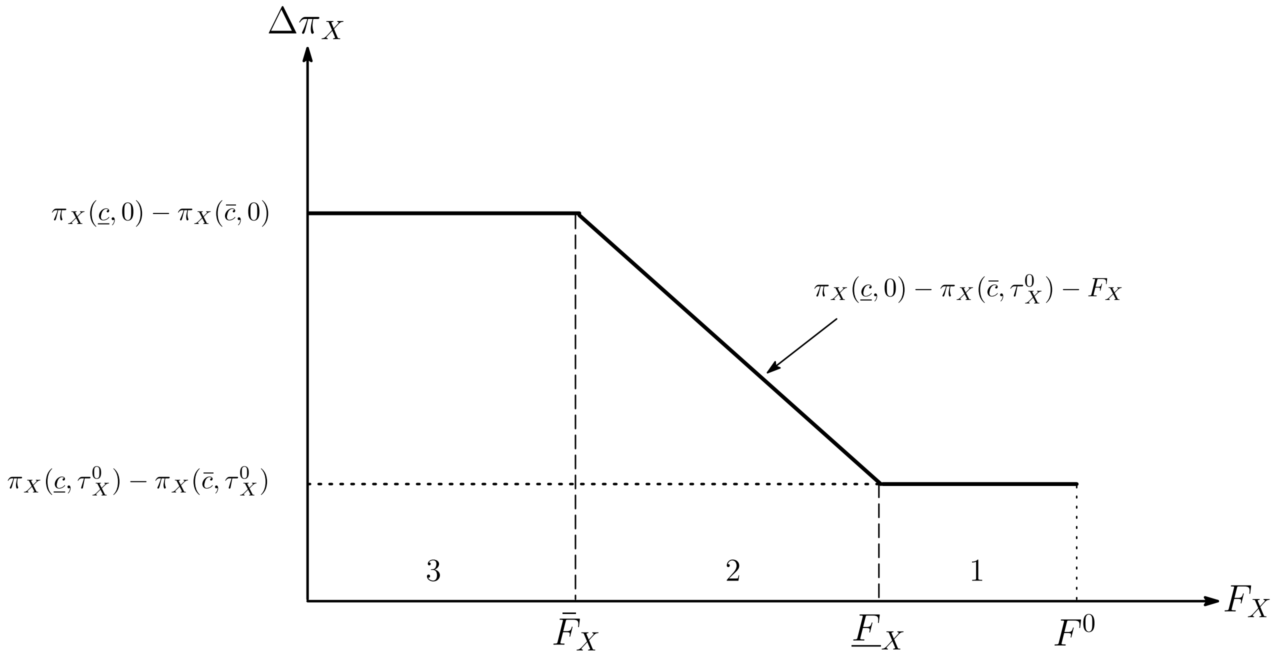


Figure 4: Trade Liberalization (A Single Foreign Firm)

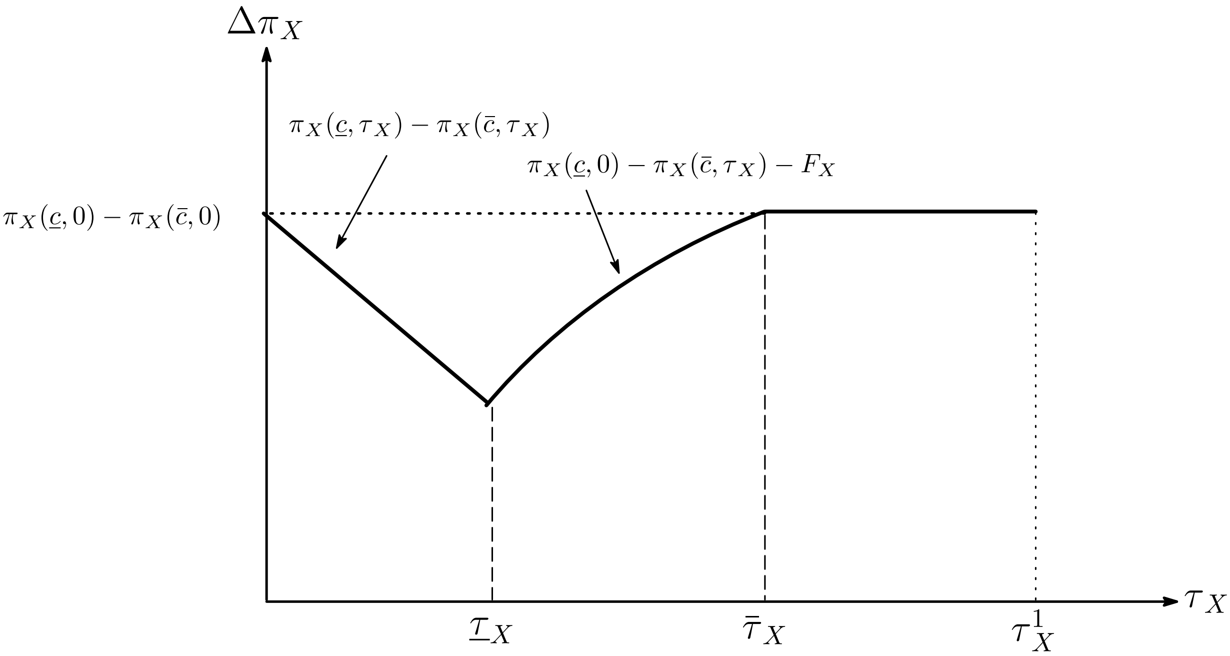


Figure 5: The Choices between Exporting and FDI when $F = F_X = F_Y$

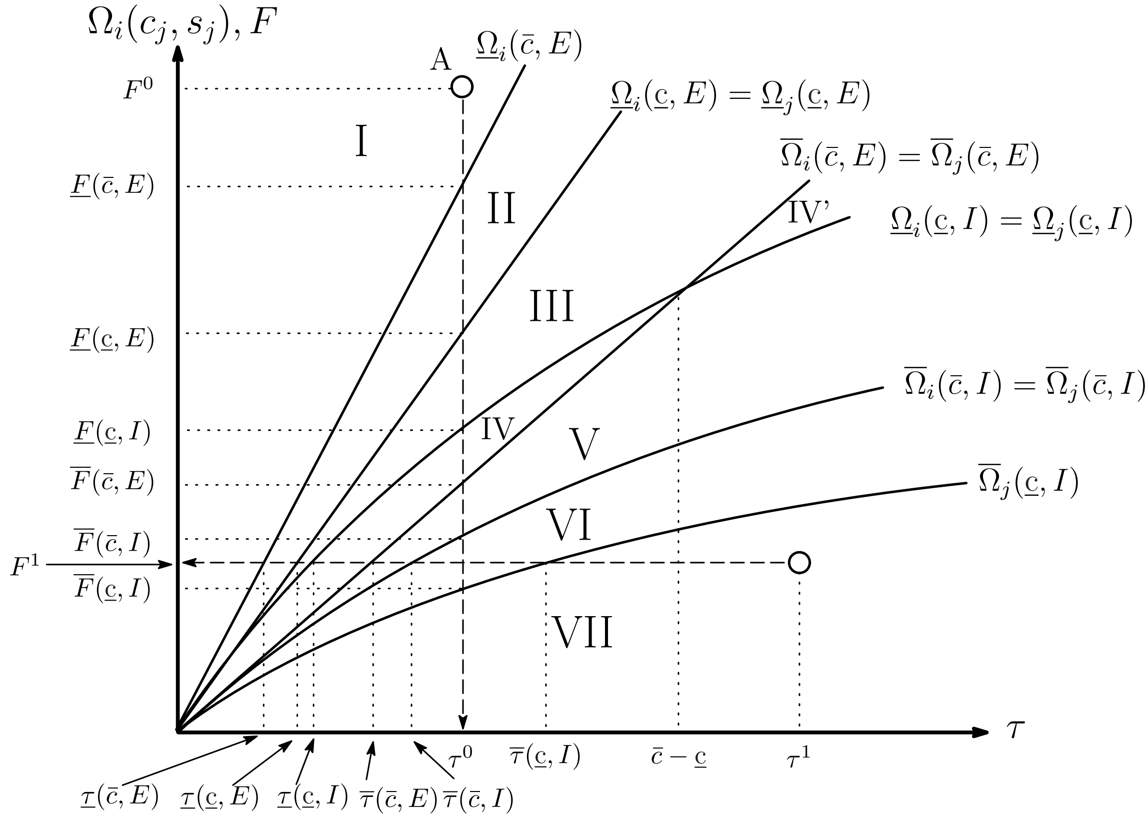


Table 1: The equilibrium locations (multilateral liberalization)

	(1st adopter, 2nd adopter)		
	Phase 1	Phase 2	Phase 3
I	(E, E)		
II	(E, E)	(I, E)	(E, E)
III	(E, E)	(I, E)	(I, E) or (E, I)
IV	(E, E)	(I, E)	(I, I)
IV'	(I, E) or (E, I)	(I, E)	(I, E) or (E, I)
V	(I, E) or (E, I)	(I, E)	(I, I)
VI	(I, I)	(I, E)	(I, I)
VII	(I, I)		

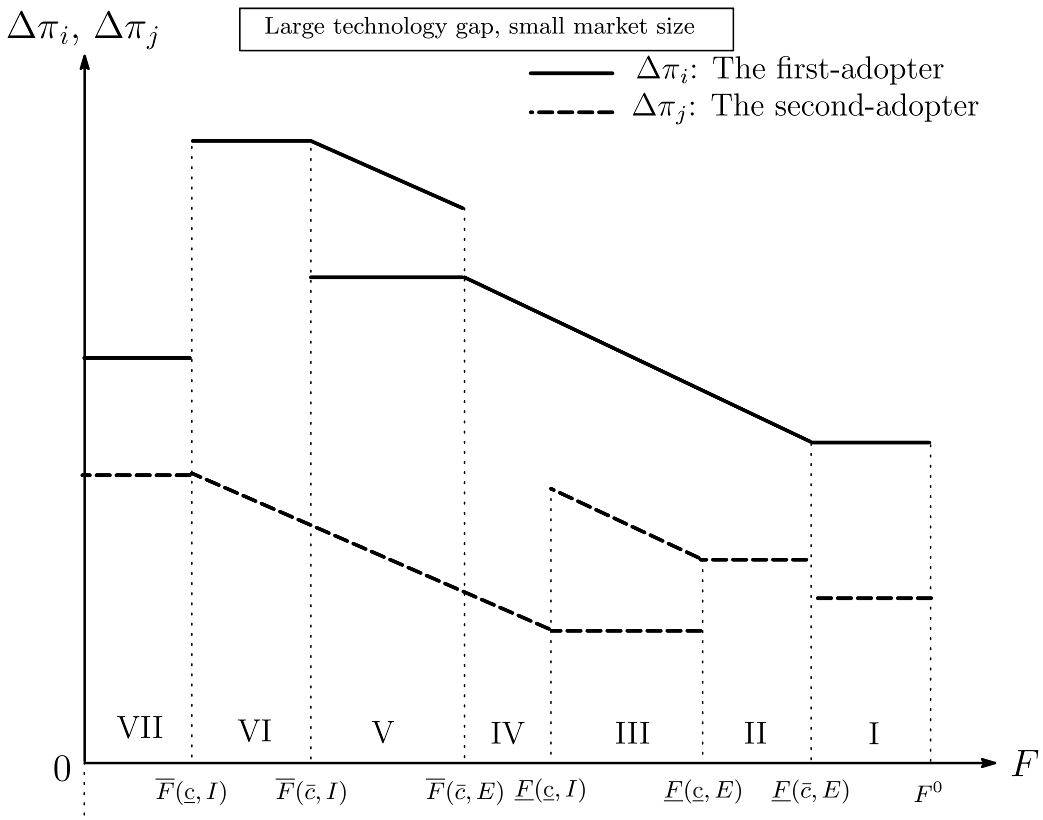
E: Exporting, I: FDI

Phase 1: Neither firm adopts the new technology

Phase 2: Only the 1st adopter adopts the new technology

Phase 3: Both firms adopt the new technology

Figure 6: Multilateral liberalization of FDI



(I, I)	$(I, E)/(E, I)$	(E, E)		Phase 1
(I, I)	(I, E)	(E, E)		Phase 2
(I, I)	$(I, E)/(E, I)$	(E, E)		Phase 3

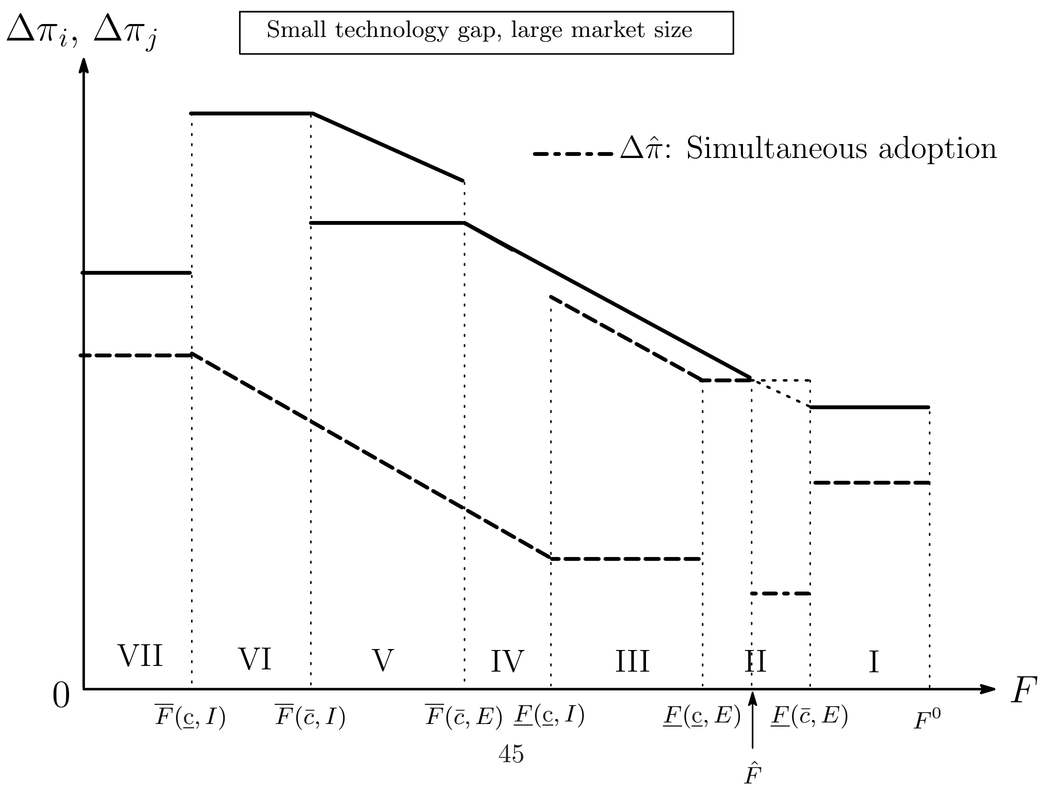


Figure 7: Multilateral trade liberalization

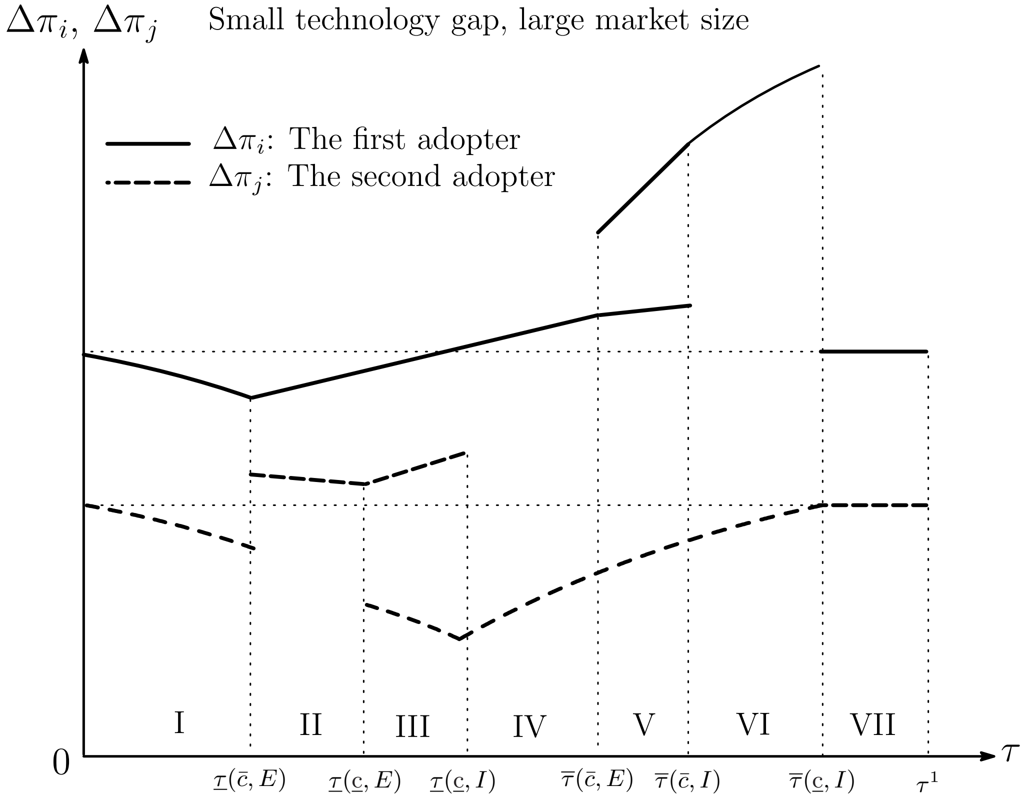


Figure 8: The Choices between Exporting and FDI when $F_X \leq F_Y$

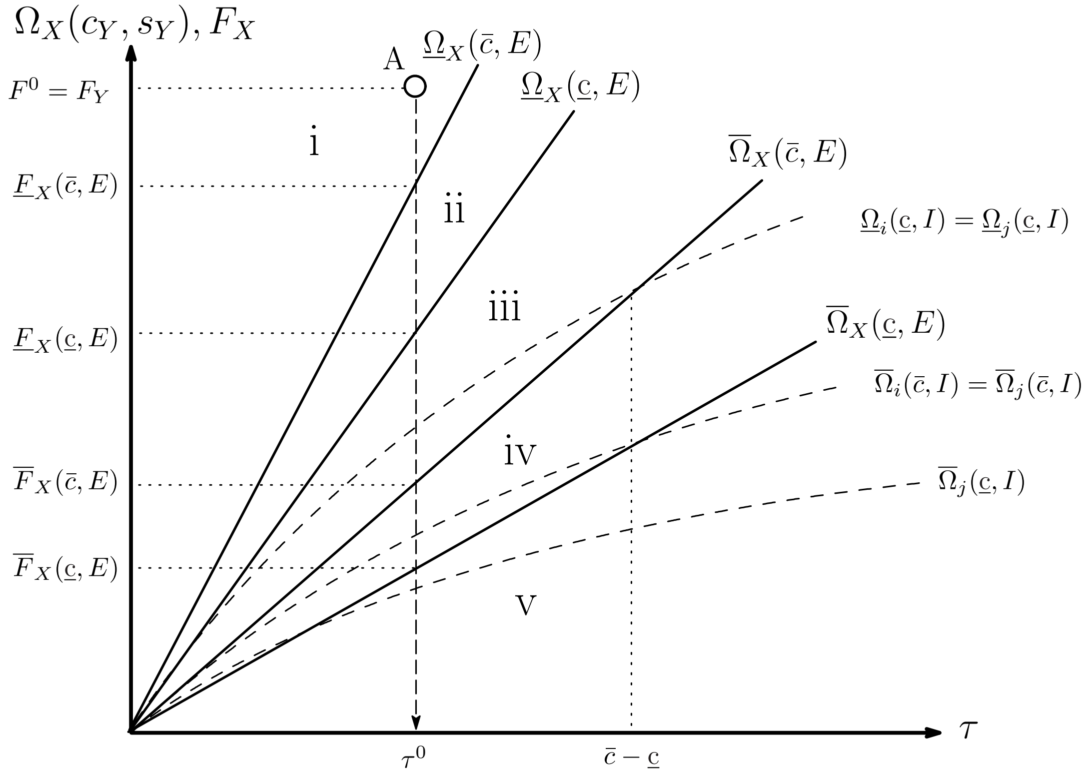


Table 2: The equilibrium locations (preferential liberalization)

	(1st adopter, 2nd adopter)						
	Firm X: 1st adopter				Firm X: 2nd adopter		
	Phase 1	Phase 2	Phase 3		Phase 1	Phase 2	Phase 3
i	(E, E)			i	(E, E)		
ii	(E, E)	(I, E)	(E, E)	ii	(E, E)		
iii	(E, E)	(I, E)		iii	(E, E)		(E, I)
iv	(I, E)			iv	(E, I)	(E, E)	(E, I)
v	(I, E)			v	(E, I)		

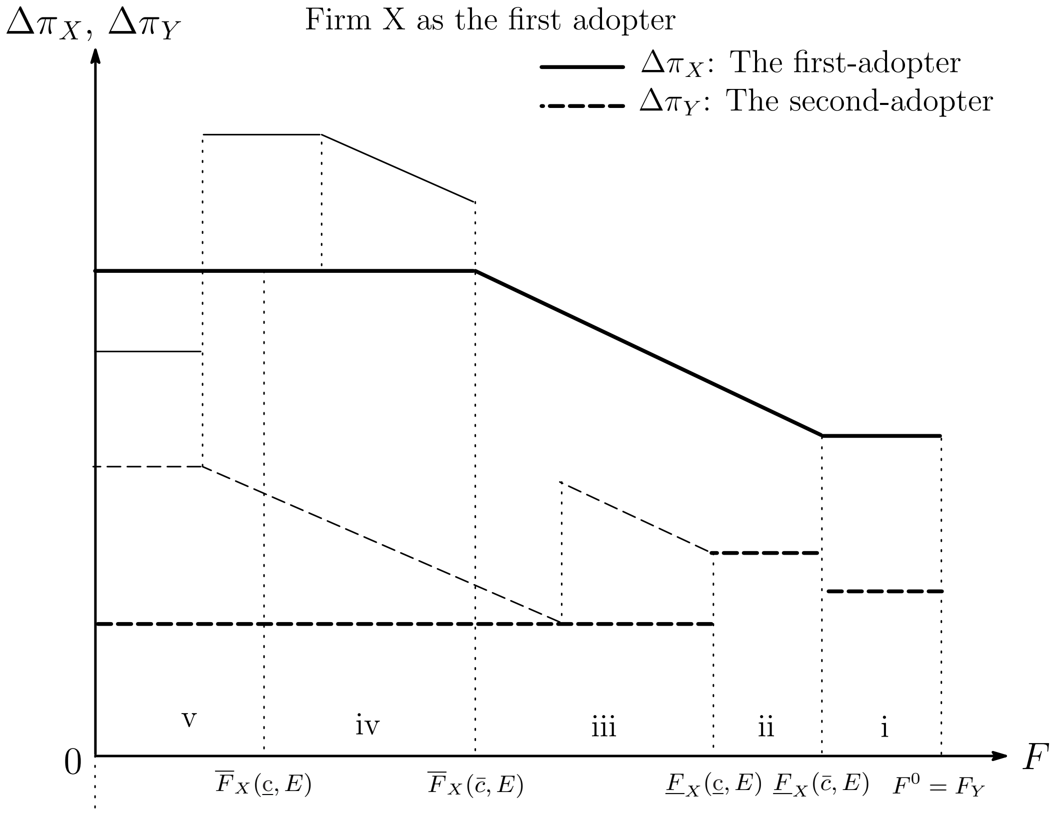
E: Exporting, I: FDI

Phase 1: Neither firm adopts the new technology

Phase 2: Only the 1st adopter adopts the new technology

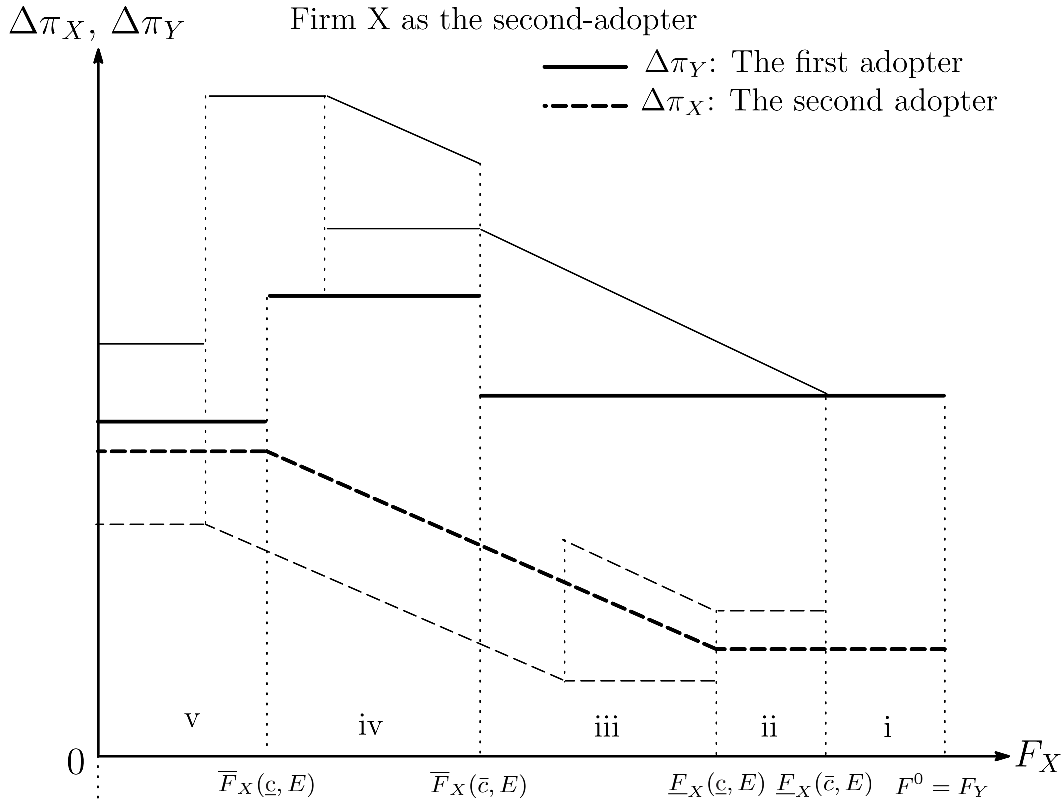
Phase 3: Both firms adopt the new technology.

Figure 9: Preferential liberalization of FDI when firm X is the first-adopter



(I, E)	(E, E)	Phase 1
(I, E)	(E, E)	Phase 2
(I, E)	(E, E)	Phase 3

Figure 10: Preferential liberalization of FDI when firm X is the second-adopter



(E, I)	(E, E)	Phase 1
(E, I)	(E, E)	Phase 2
(E, I)	(E, E)	Phase 3