Multinationals, technology transfers and spillovers

Yunyun Wan

July, 2020

Discussion Paper No.2010

GRADUATE SCHOOL OF ECONOMICS

KOBE UNIVERSITY

ROKKO, KOBE, JAPAN

Multinationals, technology transfers and spillovers

Yunyun Wan[*]

July 6, 2020

Abstract

In this paper we investigate whether multinational firms transfer the state-of-the-art technology to subsidiaries in the presence of unintended technology spillovers. It is found that the transfer is more likely when multinationals face (i) higher spillover rates, (ii) fewer local competitors, and (iii) more multinational competitors. "Forced technology transfer" to local competitors, as observed in China, harms multinationals while benefiting the host country. With endogenous entry of a local firm, however, there are cases in which forced technology transfer harms the host country.

Keywords: Multinational firms, foreign direct investment (FDI), technology transfer, technology spillovers, forced technology transfer

1 Introduction

Multinational firms are known to transfer older technologies to subsidiaries in developing countries than they do in developed countries. Mansfield and Romeo

---

[*] Graduate School of Economics, Kobe University, Japan. Email: jiangyun.wan@gmail.com

(1996) have explained this phenomenon in these words. “Because many newer technologies are inappropriate for developing countries, or are difficult and expensive to transfer there, we would expect the technology transferred to developing countries to be older than that transferred to developing countries” (p. 738).[1] There is another explanation. Since intellectual property protection is lax in developing countries compared with developed countries, multinational firms may be less willing to transfer the state-of-the-art technology to subsidiaries in developing countries lest it fall into the hands of local competitors who will subsequently use it to their advantage to compete with the multinationals [Lee and Mansfield (1996)]. In this paper we examine this second rationale.

There is a line of research investigating the strategic licensing of vintage technology to a foreign agent in the presence of unintended technology spillover. For example, Rockett (1990) considers the nature of optimal licensing contracts. Fosfuri (2000) revisits the multinational firm’s access mode selection problem previously examined by Ethier and Markusen (1996). Both Ethier and Markusen (1986) and Fosfuri (2000) implicitly assume that licensing is susceptible to technology spillovers while exporting and foreign direct investment (FDI) are not. This assumption, however, has been contradicted by empirical work documenting technology spillovers from FDI.[2]

Some authors have formally analyzed the possibilities of technology spillovers through FDI. Fosfuri et al. (2001) have developed a two-period model, based on the work by Ethier and Markusen (1998), in which a multinational firm trains a local manager at its overseas subsidiary in the first period but cannot prevent him from becoming a competitor himself in the second period. A similar labor-turnover model has been proposed by Glass and Saggi (2002). This paper

---

[1] Also see Diwan and Rodrik (1991) for the model investigating the appropriate technology transfers.

[2] See, e.g., Mansfield and Romeo (1980) for U.S. foreign direct investment, Liu (2002) for China, Kohpaiboon (2006) for Thailand, and Managi and Bwalya (2010) for sub-Saharan African countries.

contributes to this line of research, focusing, instead of analyzing the technology spillover processes, on how market competition influences multinational firms' technology choices for subsidiaries.

We begin our analysis with a simple two-stage model with one multinational and one local firm. In the first stage, the multinational firm chooses a type of technology to transfer to its subsidiary in the foreign (host) country. At the end of the first stage, part of the technical knowledge embodied in that technology spills over to the local competitor. We take the spillover rate to be exogenous, an assumption common in the industrial organization literature (see, e.g., d'Aspremont and Jacquemin 1988) and the FDI literature (e.g., Ghosh et al. 2018). In the second stage, the multinational and the local firm compete in a Cournot fashion.

This model reveals that the multinational firm transfers its state-of-the-art technology if the spillover rate is high and a vintage technology when the spillover rate is low. Though counterintuitive, this finding has the following intuitive explanation. Suppose that the multinational firm can produce each unit of output with 20 units of local labor under the old technology and 10 units of local labor under the new technology. When the spillover rate is 80 percent, the imitation of the old technology allows the local firm to produce each unit of output with (5/4) x 20 = 25 units of local labor, while that of the new technology reduces this labor requirement to (5/4) x 10 = 12.5 units; a saving of 12.5 units in labor for the local firm. If the spillover rate drops to 40 percent, the local firm can produce each unit of output with (5/2) x 20 = 50 units of labor with the old technology and with (5/2) x 10 = 25 units of local labor; a saving of 25 labor units! Thus, the transfer of a newer technology makes the local firm relatively more competitive at low spillover rates, which explains why the multinational is more reluctant to transfer the state-of-the-art technology when the spillover rate is low.

In section 3, we extend the basic model to allow for product differentiation, multiple local firms under linear demand. We also study price-setting behavior. When the products are less differentiated, when there are more local firms, and when the competition is in prices, the market becomes more competitive, discouraging the transfer the state-of-the-art technology.

The multination also faces tougher competition when there are more multinationals compete in the host country. In this case, however, stiffer competition encourages the transfer of the state-of-the-art technology (section 4). Thus, the choice of technology depends in part on the type of the competition the multinationals face.

Section 5 extends the model of section 4 to endogenize entry of a local firm and shows that . endogenous entry encourages the transfer of the state-of-the-art technology.

The Trump Administration has accused China for forcing in-bound multinational firms to hand over technologies to local Chinese firms as a pre-condition for market access. In section 6 we extend the models of section 4 and 5 to examine the consequences of such "forced technology transfer" policy. In China, "technology transfer" is enforced essentially in two ways.[3] One is through formation of joint ventures with Chinese partners. An alternative is to seek prior approval for investment from regional regulators, who however are known to impose deal-specific requirements for approval, which include submission of the technologies used in the subsidiaries and subsequently to pass the information to the local firms. In this paper, we focus on the second type of forced technology transfer in two situations.

---

[3] Details of forced technology transfer in China can be found in Hufbauer, G. C. and Lu, Z., Section 301:US Investigates allegations of forced technology transfers to China (East Asia Forum, October 3, 2017) and Branstetter, L.G., Forced technology transfer problem - And what to do about it (Peterson Institute for International Economics Policy Brief June 2018).

When forced technology spillover policy is intended to help the existing local firm acquire foreign technology, the policy of forced technology transfer harms the multinationals and benefits the local firm and local consumers. When it is intended to help a local firm enter the market, however, the outcome can be counterintuitive; namely, forced technology transfer policy can make every one worse off. Section 7 concludes.

2 The duopoly model of technology transfer with spillovers

Suppose a multinational firm's subsidiary competes with a local firm in a developing country. When does the multinational transfer its state-of-the-art technology to the subsidiary? In this section we address this question in Cournot duopoly.

Suppose that, thanks to continuous innovations, the multinational firm holds, in addition to the state-of-the-art technology, a cache of vintage technologies that can be transferred to the subsidiary. Assume that the technologies available for transfer are represented by the compact set $F = [f_B, f_A]$, where f_B is its oldest technology while f_A is its state-of-the-art technology. Assume that for any $f, f' \in F$, $f > f'$ implies that f is a Hicks-neutral improvement of f'.

The literature has identified labor turnover and reverse engineering as two common channels of unintended spillovers.[4] Although managers and engineers may be lured from the multinational firm, however, they may not be able to carry with them the entire knowledge embodied in the transferred technology. Similarly, reverse engineering may not result in a perfect duplication of the multinational firm's technology, especially when it is a process innovation. We

---

[4] See Fosfuri et al. (2001) and Glass and Saggi (2002).

thus assume that the local firm can imitate the multinational's technology f only with $\sigma(\times 100)$ percent accuracy, where $\sigma \in (0,1]$ denotes the spillover rate, assumed exogenous. This signifies that if the multinational firm transfers technology $f \in F$ to its subsidiary, the local firm acquires the technology σf. If $\sigma = 1$, spillovers are perfect; the local firm acquires the identical technology the multinational firm has transferred whereas If $\sigma = 0$, the local firm learns absolutely nothing from the multinational firm's local presence. We assume, to keep things simple, that the local firm's current technology is so inefficient that it imitates any technology the multinational transfers. We also assume until section 5 that the multinational cannot force the local firm to exit even with the transfer of the state-of the-art technology.

In the analysis to follow, we find it easier to work with the set of unit (minimum) cost $C = [c_A, c_B]$ instead of with the technology set F, its dual, where c_A represents its state-of-the-art (best) technology f_A and $c_B(> c_A)$ the oldest-technology f_B. In terms of cost functions, if the multinational firm transfers technology $c \in C$, the local firm acquires the technology $c/\sigma(> c)$.

Technology transfers may impose additional costs to multinationals.A empirical study by Teece (1977) has found that there are great variations in costs of technology transfer across types of multinational activity. Transfer costs are almost negligible in engineering-based industries such as chemicals, where technological information can be embodied in equipment and blueprints but are significant in industries in which information relates to operations of equipment, quality control, organization and other procedures.[5] Teece (1977) has also found that an older technology is generally cheaper to transfer than a newer technology, although this monotonicity may break down as regards really old technologies. Letting $T(c)$ denote the cost of transferring technology c to the subsidiary, we

---

[5] Interestingly, Teece (1977) has found cases in which transfer costs were less for international than for domestic technology transfer.

thus assume as a first approximation that $T(c)$ is continuously differentiable, and write the first derivative $T'(c) < 0$ and the second derivative $T''(c) > 0$.[6] We ignore the cost of imitation to the local firm.[7]

The main question we address in this paper is when the multinational firm transfers its state-of-the-art technology to the subsidiary in the presence of technology spillovers. In the remainder of this section we investigate this question in the two-stage game. In the first stage the multinational firm chooses a technology $c \in C$ to transfer to the subsidiary. In the second stage, the local firm acquires the technology c/σ through technology spillovers and then the two firms engage in Cournot competition in the homogeneous product market.

Let $p(q_m + q_h)$ represent the host-country inverse demand function, where q_m and q_h denote the quantities of output sold by the multinational firm (firm m) and the host-country (local) firm (firm h), respectively. The (net) profits for the multinational firm and the local firm are defined, respectively, by

$$\pi_m = [p(q_m + q_h) - c]q_m - T(c),$$

and

$$\pi_h = [p(q_m + q_h) - c/\sigma]q_h.$$

We assume the demand function is continuously differentiable and weakly concave.

Assumption 1: $p' < 0$. $p'' \leq 0$.

In the second stage, the firms choose quantities to maximize the respective profit, given the technologies. The first-order conditions are

---

[6] Teece (1977) however has also noted the possibility of non-monotonicity; really old technologies may be very costly to transfer if current generations of managers and engineers are unfamiliar with such antiquated technologies.

[7] Gallini (1992) examines the role of imitation costs.

$$\partial \pi_m / \partial q_m = p - c + p' q_m = 0$$

$$\partial \pi_h / \partial q_h = p - c/\sigma + p' q_h = 0$$

which can be solved for a (unique) Nash equilibrium $(q_m(c), q_h(c))$. Substituting these quantities, we obtain the equilibrium profit to the multinational firm as $\pi_m(c)$. In the first stage, the multinational chooses technology c to maximize this profit. Differentiation yields

$$\begin{aligned} d\pi_m(c)/dc &= \partial \pi_m(c)/\partial c + (\partial \pi_m(c)/\partial q_h(c))(\partial q_h(c)/\partial c) - T'(c) \\ &= -q_m + q_m p' \partial q_h(c)/\partial c - T'(c). \end{aligned} \tag{1}$$

The first two terms in the second line highlight the fundamental tradeoff the multinational faces in the presence of spillovers. A unit reduction in the multinational's cost increases its profit by q_m; that is, $\partial \pi_m(c)/\partial c = -q_m < 0$. This is the direct or efficiency effect of transferring a newer technology. Without spillovers, that is all there is. With spillovers, a newer technology reduces the local firm's unit cost by $1/\sigma \geq 1$, as illustrated in the introduction, enabling the local firm to expand output and decreasing the multinational firm's profit by $q_m p' \partial q_h(c)/\partial c > 0$. This is the indirect or spillover effect, captured by the second term in (1). The multinational's choice of technology hinges on the relative magnitude of these two opposite effects. When $\sigma = 1$, the efficiency effect dominates the spillover effect, so $d\pi_m(c)/dc < 0$, resulting in the transfer of the state-of-the-art technology. If $\sigma < 1$, a transfer of a newer technology reduces the local competitor's cost proportionately more than it does the multinational firm's cost. Furthermore, the lower the spillover rate, the greater is this proportionality, as explicated in the introduction. If the spillover rate is low enough, therefore, the spillover effect can dominate the efficiency effect so that $d\pi_m(c)/dc > 0$; a transfer of a newer technology decreases the multinational's profit. The presence of the transfer cost $T(c)$ only adds bias against transfer of a newer technology.

To make the above statement lucid, differentiate the first-order conditions to obtain

$$\begin{pmatrix} 2p' + p''q_m & p' + p''q_m \\ p' + p''q_h & 2p' + p''q_h \end{pmatrix} \begin{pmatrix} dq_m \\ dq_h \end{pmatrix} = \begin{pmatrix} 1 \\ 1/\sigma \end{pmatrix} dc.$$

Solving this system, we find that

$$\partial q_h(c)/\partial c = [(2p' + p''q_m)/\sigma - (p' + p''q_h)]/\Delta$$

where $\Delta \equiv 3(p')^2 + p'p''(q_m + q_h) > 0$. Substituting this derivative into (1) and collecting terms, we obtain

$$d\pi_m(c)/dc = q_m \left\{ 2(p')^2(\frac{1}{\sigma} - 2) + p'p'' \left[(\frac{1}{\sigma} - 1)q_m - 2q_h \right] \right\} /\Delta - T'(c) \quad (2)$$

If $d\pi_m(c)/dc > 0$, the multinational transfers an older technology. The first term in braces is positive if and only if $\sigma < 1/2$. The second term is positive if $\sigma < 1/3$ because $c < c/\sigma$ implies $q_m > q_h$. Given that $T'(c) < 0$, $\sigma < 1/3$ is sufficient for satisfying the inequality $d\pi_m(c)/dc > 0$. On the other hand, if σ is sufficiently close to one, the expression in braces is negative, so $d\pi(c)/dc$ can be positive or negative or zero, depending on the marginal cost of technology transfer. If $d\pi_m(c)/dc = 0$, this determines the optimal technology choice. If $d\pi(c)/dc < 0$, the multinational firm transfers the state-of-the-art technology.

Proposition 1: (A) If $\sigma < 1/3$, the state-of-the-art technology is never transferred. (B) The state-of-the-art-technology is transferred only if σ is sufficiently close to one.

Proposition 1 contrasts with the conventional view that the multinational is less willing to transfer its best technology when a technology can fall into the local competitor's hands. The intuitive explanation of this result reflects two facts. One is that when two firms use the identical technology due to perfect spillovers then the transfer of the best technology maximizes profit for the multinational firm. By analogy then if the spillover rate is sufficiently high, there still exists a strong motive for transferring the state-of-the-art technology. However as illustrated in the introductory section of this paper, when the spillover rate is low enough, the transfer of a new technology makes the local firm relatively more competitive. The optimal transfer strategy reflects the balance of these two effects.

3 Linear Demand, Product Differentiation, and Price Competition

This section has two objectives. One is to sharpen the results in proposition 1. To do so, we firstly assume linear demand and set $p'' = 0$. Secondly, from proposition 1 we know that if the transfer cost $T(c)$ rises sharply enough, the multinational will never transfer the state-of-the-art technology. We remove this bias by ignoring the transfer cost in our subsequent analysis.

Our second objective is to understand how competitiveness of the local market affects the multinational's technology choice. Competitiveness depends the number of local firms and other multinational firms there are in the local market as well as the degree of product substitutability among them. The market also becomes more competitive when firms compete in prices instead of in quantities. In this section we first consider the effects of multiple local firms and the degree of product substitutability, and then the effect of price competition. The case of multiple multinational firms is discussed in the next section.

Assume that the multinational firm competes with $n \geq 1$ local firms and that its product is differentiated from the locally produced products (for simplicity, the locally produced goods are considered homogeneous). Firms still compete in quantities.

Suppose that the local firms are symmetric and produce Q_h units of output collectively. A typical local firm produces $q_h = Q_h/n$. The demand functions faced by the multinational and by a typical domestic firm are given by

$$p_m = a - q_m - bQ_h$$

$$p_h = a - Q_h - bq_m$$

where $b \in [0, 1]$ measures the degree of product substitutability. Assume that the spillover rate is common to all local firms, which results in symmetry among local firms. The multinational and a typical local firm receive the profits $\pi_m = (p_m - c)q_m$ and $\pi_h = (p_h - c/\sigma)q_h$, respectively. The equilibrium quantities are

$$q_m(c) = \frac{(n + 1 - nb)a - (n + 1)c + nbc/\sigma}{2(n + 1) - nb^2}$$

$$q_h(c) = \frac{(n + 1 - nb)a - (n + 1)c + nbc/\sigma}{2(n + 1) - nb^2}$$

The multinational firm's profit equals $\pi_m(c) = q_m(c)^2$. Differentiating, we obtain

$$d\pi_m(c)/dc = \frac{-(n + 1) + nb/\sigma}{2(n + 1) - nb^2} q_m.$$

Thus the multinational transfers the state-of-the-art technology if and only if

$$\sigma > nb/(n+1).$$

Observing that the right-hand side expression is increasing both in b and in n gives us

Proposition 2 Under linear demands with product differentiation:

(a) The multinational firm transfers the state-of-the-art technology if and only if $\sigma \geq nb/(n+1)$.

(b) The multinational firm is less likely to transfer the state-of-the-art technology when it competes with more local competitors or when its product is more substitutable to the local firms' products

Setting $n = b = 1$, we can sharpen proposition 1.

Corollary 1. Under linear demand with $n = b = 1$, the state-of-the-art technology is transferred if and only if $\sigma > 1/2$.

More generally, linear demands make the multinational's profit function convex in $c \in [c_A, c_B]$ so the multinational transfers the state-of-the-art technology c_A if $\sigma > nb/(n{+}1)$ and c_B if $\sigma < nb/(n{+}1)$. If $\sigma = nb/(n{+}1)$, the multinational firm is indifferent among all the options.[8]

Proposition 2 says that the transfer of the state-of-the-art technology is less likely when the market is more competitive in that there are more local competitors and there is less of product differentiation. Since competition is tougher in price competition than in quantity competition, we expect a similar result from price competition. To verify this expectation, consider the Hotelling duopoly model, where consumers are distributed uniformly over the unit line $[0, 1]$ while the multinational and the local firm occupy the end points 0 and 1.

---

[8] The corner solutions can be avoided if the transfer cost is retained.

The equilibrium price is

$$p_m = (3t + 2c + c/\sigma)/3;$$

$$p_h = (3t + 2c/\sigma + c)/3,$$

where t is the unit 'transportation' cost. The multinational firm produces

$$q_m(c) = \frac{3t - c + c/\sigma}{6t}$$

and earns the profit $\pi_m(c) = (q_m(c))^2$. Differentiating, we find

$$d\pi_m(c)/dc = q_m(-1 + 1/\sigma)/6t > 0$$

for all $\sigma < 1$.

Proposition 3. In the Hotelling model, the multinational firm never transfers its state-of-the-art technology for all $\sigma < 1$.

4 Competition among multinationals

A multinational firm may also face competition with other multinationals in the host country. How does the rivalry among multinationals affect the technology choice? In this section we consider this question.

Suppose that M symmetric multinational firms have the identical technology set C. To keep things simple, let us suppose that they face a single local firm and that all firms produce homogenous goods. The game proceeds as follows. In the first stage M multinationals labeled by $i = 1, 2..., M$ simultaneously choose technologies $c_i \in C$ to transfer to their subsidiaries in the host country. Assume that all multinationals' technologies spill over to the local firm so that the local firm imitates the best technology available. Thus, the local firm acquires the technology

$$c_h = \min(c_1, c_2, , , , , c_M)/\sigma,$$

In the second stage, all firms compete in quantities. A typical multinational i has the profit

$$\pi_i = (a - q_i - \sum_{j \neq i} q_j - q_h - c_i)q_i.$$

while the local firm has the profit:

$$\pi_h = (a - \sum_i q_i - q_h - c_h)q_h.$$

In equilibrium they produce

$$q_i = (a - (M+1)c_i + \sum_{j \neq i} c_j + c_h)/(M+2)$$

$$q_h = (a + \sum_i c_i - (M+1)c_h)/(M+2).$$

Moving back to the first stage, each multinational i chooses technology c_i to maximize the profit

$$\pi_i = (q_i)^2 = [a - (M+1)c_i + \sum_{j \neq i} c_j + c_h]^2/(M+2)^2 \qquad (3)$$

given the other multinational firms' technology choices c_j.

Define

$$c_{-i} = min(c_1, c_2, , , c_{i-1}, c_{i+1}, , , , , c_M)$$

Then the local firm has the technology $c_h = min(c_i, c_{-i})/\sigma$.

If multinational firm i chooses a technology $c_i < c_{-i}$, then $c_h = c_i/\sigma$ so that

(3) is written

$$\pi_i = [a - (M+1)c_i + \sum_{j \neq i} c_j + c_i/\sigma]^2/(M+2)^2$$

We have that

$$\partial\pi_i/\partial c_i = 2[-(M+1) + 1/\sigma][a - (M+1)c_i + \sum_{j \neq i} c_j + c_i/\sigma]/(M+2)^2.$$

If $\sigma > 1/(M+1)$, $\partial\pi_i/\partial c_i < 0$ so multinational i transfers the state-of-the-art technology. If $\sigma < 1/(M+1)$, $\partial\pi_i/\partial c_i > 0$ so it transfers the technology $c_i = c_{-i}$.

Alternatively, if multinational firm i transfers $c_i \geq c_{-i}$, then $c_h = c_{-i}$ so the profit in (3) is decreasing in c_i. Therefore, multinational firm i transfers the technology $c_i = c_{-i}$ for all $\sigma > 0$. Now it is straightforward to demonstrate

Proposition 4. Suppose that $M \geq 2$ symmetric multinational firms compete with one local firm. With Cournot competition, homogeneous goods and linear demand, the following are the subgame-perfect Nash equilibrium outcomes.

(i) For $\sigma > 1/(M+1)$, all multinationals transfer the state-of-the-art technology c_A.

(ii) For $\sigma < 1/(M+1)$, all multinationals transfer any identical technology $c \in [c_A, c_B]$.

(iii) The more multinationals there are, the more likely the state-of-the-art technology is transferred.

Two remarks are in order. First, result (ii) says that there is a continuum of subgame-perfect Nash equilibria if $\sigma < 1/(M+1)$. However, the equilibrium profit

$$\pi_i = (a - 2c + c/\sigma)^2/(M+2)^2$$

is monotone increasing in c, so in the Pareto-dominant equilibrium all multinationals transfer the oldest technology. Second, result (iii) contrasts sharply with proposition 2. Proposition 2 says that increased competition discourages transfer of the state-of-the-art technology while proposition 3 says the opposite. With more multinationals competing, even if the local firm acquires a better technology and expands its output, its effect is spread out among all the multinationals, causing each multinational to suffer only a small loss of market share. On the other hand, each multinational can capture a large market share by transferring the state-of-the-art technology, given other multinationals' technology choices. Thus, unilateral transfer the state-of-the-art technology expands each multinational's market share and hence its profit. This explains proposition 3.

In contrast, with more local competitors, a technology spillover causes all local firms to expand output, causing a large loss of market share for the multinational firm and this loss is greater, the more local firms there are. The prospect of a large loss of market share discourages transfer of the state-of-the-art technology. This accounts for proposition 2.

5 Entry deterrence

As we have seen, the multinationals do not transfer the state-of-the-art technology when the spillover rate is low and when they face tougher competition from the local firms. How do these results change if the multinationals can force the local firms to exit the market, or equivalently if they can deter entry of local firms? We turn to this question in this section.

Suppose that M multinationals face a single local firm, as in section 4. The game is modified as follows. In the first stage, M multinationals simultaneously choose c_i to transfer to their respective subsidiaries. In the second stage, the local firm obtains the best technology among the transferred technologies through spillovers and decide whether to enter the market (equivalently, to exit the market). If the local firm stays out (or exists), M multinationals compete in quantities. If the local firm is in the market, $M+1$ firms compete. In the analysis below we focus on the entry version of the model (the analysis of exit is analogous).

Suppose that all multinationals transfer technology c. Then, if the local firm enters, it has the net profit

$$v_h(c) = [a - (M+1)c/\sigma + Mc]^2/(M+2)^2 - e$$

where $e > 0$ is the fixed entry cost. Let $\bar{c}_D$ denote the value of c at which the above expression vanishes:

$$v_h(\bar{c}_D) = [a - (M+1)\bar{c}_D/\sigma + M\bar{c}_D]^2/(M+2)^2 - e = 0 \tag{4}$$

We call $\bar{c}_D$ the deterrence technology because entry is deterred when all multinationals transfer $\bar{c}_D$ or an older technology. Assume that entry deterrence is feasible.

Assumption 2: $\bar{c}_D \in (c_A, c_B]$.

Assumption 2 implies that $v_h(c_A) > 0$; entry occurs if the state-of-the-art-technology is transferred.

If entry is deterred, each multinational firm receives the profit

$$\pi^D = (a - \bar{c}_D)^2/(M+1)^2 \tag{5}$$

(no multinationals transfer an older technology than $\bar{c}_D$).

Proposition 5. Suppose that $M \geq 2$ symmetric multinationals face one local entrant and focus on the Pareto-dominant equilibria. With Cournot competition, homogeneous goods and linear demand, the following are the subgame-perfect Nash equilibrium outcomes.

(i) If $\sigma < 1/(M+1)$, all multinationals transfer technology $\overline{c}_D$ to deter entry.

(ii) If $\sigma > 1/(M+1)$, all multinationals transfer technology $\overline{c}_D$ to deter entry if and only if

$$(M+1)\left[1/\sigma - (1+M)\right]\{a - [(M+1)/\sigma - M]c_A\} + (M^2+M+1)(M+2)\sqrt{e} > 0. \tag{6}$$

(Proof in the appendix)

For $\sigma < 1/(M+1)$, without entry deterrence the multinationals transfer the oldest technology (proposition 4) while with entry deterrence they transfer the deterrence technology. In the latter case the multinationals profits are greater because (i) they use the deterrence technology which is more efficient than the oldest technology and (ii) they do not complete with the local firm. But these are the profits the multinationals must forgo if transfer the state-of-the-art technology. In other words, the transfer of the state-of-the-art technology has a higher opportunity cost when entry deterrence is possible. For this reason, although they transfer the state-of-the-art technology without entry deterrence if $\sigma > 1/(M+1)$, this condition is not sufficient when entry deterrence is a possibility; sufficiency requires that condition (6) be reversed.

It is straightforward to show that (6) is more likely to hold when a is low, c_A is high and e is high. A low demand (a) and a high c_A imply that the state-of-the-art technology does not increase the multinationals' profits sharply. A high entry cost e implies that entry can be deterred with a more efficient deterrence technology, resulting in greater profit. Thus, when (6) holds, the multinationals deters entry although $\sigma > 1/(M+1)$.

Proposition 6: Given $\sigma > 1/(M+1)$, the state-of-the-art technology is more likely to be transferred when

(i) the host-country market demand (intercept) is greater,

(ii) the local firm has a lower entry cost,

(iii) the state-of-the-art technology is relatively more efficient.

6 Forced technology transfer

As mentioned in the introduction, China has been accused of demanding complete disclosures of the technologies from multinationals as a pre-condition for market access. The problem for multinationals is that the technical information embodied in that technology is often passed on to the local firms. What is the consequence of such a policy? In this section we address this question.

This policy is commonly known as "forced technology transfer." Here, however, it is renamed "forced technology handover" or FTH for short, as consistency demands that the term "transfer" refer to the installment of a technology by a multinational in its subsidiary.

Suppose that the multinational(s) cannot deter entry and consider the equilibrium in which the multinationals transfer the state-of-the-art technology in the absence of FTH. Then, since "forced technology handover" is equivalent to setting $\sigma = 1$, FTH has no impact on the choice of technology by the multinationals. However, FTH enables the local firm to acquire the state-of-the-art technology c_A and makes it more competitive, implying lower profits for the multinationals and increased profit for the local firm. The acquisition of a more efficient technology by the local firm boosts industry output, lowering the price to the benefit of consumers.

Consider alternatively the cases in which the multinationals transfer the oldest technology without FTH. Then the transfer of the state-of-the-art technology that occurs under FTH precludes the optimal technology transfer and results in lower profits for the multinationals, while the acquisition of the best technology raises profit to the local firm and the higher output that results benefits consumers.

Proposition 7. In the models of sections 3 and 4, where the possibility of entry deterrence is ruled out, forced technology handover decreases the multinational firm's profit while increasing the local firms' profits and the host-country's consumer welfare.

Next, let's take a look at how the results above change if entry is endogenous. To investigate this question, define the deterrence technology $\widetilde{c}_D$ with FTH by

$$(a - \widetilde{c}_D)^2/(M + 2)^2 - e = 0. \tag{7}$$

A comparison of (4) with (7) indicates $\widetilde{c}_D > \overline{c}_D$; that is, with FTH it takes an older and less efficient technology to deter entry. Deterred entry under FTH assures the multinationals of the profit

$$\pi^D_{FT} = (a - \widetilde{c}_D)^2/(M + 1)^2 < \pi^D.$$

If a multinational firm deviates by transferring the state-of-the-art technology, entry ensues, yielding the profit

$$\pi^d_{FT} = [a - (M + 1)c_A + (M - 1)\widetilde{c}_D + c_A]^2/(M + 2)^2$$

for a deviating multinational, and $\pi^D_{FT} > \pi^d_{FT}$ if and only if

$$a + M(M + 1)c_A - (M^2 + M + 1)\widetilde{c}_D > 0.$$

Case	Spillover rate	(6)	(8)	Without FTH	With FTH
1	$\sigma < 1/(M+1)$	N.A.	Holds	No Entry	No Entry
2			Fails		Entry
3	$\sigma > 1/(M+1)$	Holds*	Holds		No Entry
4		Holds	Fails		Entry
5		Fails	Fails*	Entry	

Table 1: Summary of conditions for entry deterrence

Substituting for $\widetilde{c}_D$, we can rewrite this condition as

$$-M(M+1)(a-c_A)+(M+2)(M^2+M+1)\sqrt{e}>0 \tag{8}$$

Thus, if condition (8) holds, there is no deviation from deterred entry.

Proposition 8. Under "forced technology transfer" policy, entry is deterred with the transfer of the technology $\widetilde{c}_D$ if and only if condition (8) holds. If this condition is reversed, the multinational firms transfer the state-of-the-art technology and accommodate entry.

Condition (8) is more likely to hold when the demand is low, the entry cost is high, and the state-of-the-art technology is less efficient (c_A is higher). The intuition is similar to the one given before proposition 6. A higher entry cost makes entry deterrence less costly because the multinationals can use a more efficient deterrence technology. If the demand is low and the state-of-the-art technology is not that efficient, its transfer does not raise dramatically the multinational's profit. Both these facts make entry deterrence more attractive to multinationals compared with entry accommodation.

The table below compares the equilibrium outcomes with and without FTH from propositions 5 and 8. (The condition with an asterisk (*) is implied by the corresponding un-starred condition.)

In cases (1) and (3), entry is deterred with and without FTH. These cases occur when the demand is low, the entry cost is high and the state-of-the-art technology is relatively inefficient; that is, under condition (8). With FTH, the multinational firms transfer the older deterrence technology $\widetilde{c}_D(> \overline{c}_D)$, which makes the subsidiaries less efficient and decreases profits. Transfer of the less efficient deterrence technology also raises the price and lowers consumer welfare. Thus, FTH makes both the multinationals and the host country worse off.

In cases (2) and (4), entry is deterred without FTH and accommodated with FTH. These cases occur when the demand is high, the entry cost low and the state-of-the-art technology relatively efficient; that is, when condition (8) is reversed. The host country's welfare is higher with FTH because the local firm enters with the state-of-the-art technology instead of being deterred, and a lower price benefits local consumers. Comparing entry deterrence with entry accommodation, a typical multinational's profit changes from π^D given in (5) to $\pi_{FT}^A = (a - c_A)^2/(M+2)^2$. We have that

$$\pi^D - \pi_{FT}^A = (a - \overline{c}_D)^2/(M+1)^2 - (a - c_A)^2/(M+2)^2 > 0$$

$$\Longleftrightarrow a - (M+2)\overline{c}_D + (M+1)c_A > 0.$$

Substituting for $\overline{c}_D$, we can write the last inequality as

$$(M+1)^2\sqrt{e} + a(M+1)(1/\sigma - 2) + (M+1)[(M+1)/\sigma - M]c_A \geq 0 \qquad (9)$$

We can show that this condition holds whenever condition (6) holds. Thus, the multinationals are always harmed by FTH.

In case (5), entry is accommodated with and without FTH. Since the local firm competes with or without FTH, the welfare results are similar to those given in proposition 7; FTH decreases the multinational firms' profit while raising the local firm's profit and improving host country consumer welfare at the same

	No entry/No entry	No entry/Entry	Entry/Entry
$M = 1$	$a < 5.50$	$5.50 \leq a < 9.73$	$a \geq 9.73$
$M = 5$	$a < 8.23$	$8.23 \leq a < 11.48$	$a \geq 11.48$
$M = 8$	$a < 11.14$	$11.14 \leq a < 15.57$	$a \geq 15.57$
$M = 10$	$a < 13.11$	$13.11 \leq a < 18.36$	$a \geq 18.36$

Table 2: Illustration of Proposition 9

time. We summarize the above findings in

Proposition 9

(i) FTH always harms the multinationals.

(ii) In cases (1) and (3), entry is deterred with or without FTH. As a result, FTH also harms the local firm and host-country consumers.

(iii) in cases (2) and (4), entry is deterred without FTH and accommodated with FTH. FTH benefits the local firm and host-country consumers.

(iv) In case (5), entry is accommodated with and without FTH. FTH benefits the local firm and consumers.

Table 2 illustrates proposition 9. To find the ranges of a we fix $e = c_A = 1$ and $\sigma = 0.7$. The descriptions in the top row indicate the equilibrium outcomes without/with FTH. The table confirms that entry is more likely to be deterred when the market size is smaller or when there are more multinationals. It also shows that FTH facilitates entry of the local firm when the market size is in the intermediate range (the middle column).

7 Concluding remarks

It is well known that multinational firms transfer older technologies to subsidiaries in developing countries than they do in developed countries. One can explain this fact by an appeal to the notion of appropriate technology transfer, i.e., the complementarity between technology and skill levels of local workers. Alternative and complementary to it is another explanation that emphasizes strategic aspects of technology transfer. Multinational firms are said to be reluctant to transfer the state-of-the-art technology to countries with weak protection of intellectual property lest it be used by the local imitator to compete more aggressively them. In this paper we apply the standard oligopoly models to evaluate this second rationale and find the result that contrast sharply with it, that is, we find that the multinational firms are more likely to transfer the state-of-the-art technology when the spillover rate is high.

We also find these results. When the multinational firm faces more local competitors, it is less likely to transfer the state-of-the-art technology. By contrast, when it faces more multinational rivals, the multinational is more likely to transfer the state-of-the-art technology. When the local firm's entry is endogenous, the multinational firms are less likely to transfer the state-of-the-art technology than when the local firm is already in the market.

We also apply our models to understand the effect of "forced technology transfer policy", a common practice in China. When the wholly owned subsidiaries of multinational firms are required to hand over their technologies to the local governments as a pre-condition for market access, who later pass them on to the local firms, it is no surprise that the multinationals' profits decrease and the host country's welfare rises. With endogenous entry, however, forced technology transfer policy can be harmful to both the multinationals and to the host country. This can occur when, for example, the market demand is sufficiently small that entry is deterred even under forced technology transfer policy.

To save space we have analyzed a limited number of cases but it is possible to explore other possibilities. For example, we can extend our analysis to the case when the multinationals and local firms export to other national markets. Another interesting scenario is that the local firm can innovate based on the acquisition of foreign technology. We leave these extensions for future work.

Appendix

Proof of Proposition 5. Suppose that in equilibrium entry is deterred. If multinational firm 1, say, deviates by transferring a better technology $c_1 < \bar{c}_D$, the local firm enters with the acquired technology c_1/σ, yielding to multinational 1 the profit

$$\pi_1^d = [a - (M+1)c_1 + (M-1)\bar{c}_D + c_1/\sigma]^2/(M+2)^2$$

Differentiating,

$$\partial \pi_1^d / \partial c_1 = 2[a - (M+1)c_1 + (M-1)\bar{c}_D + c_1/\sigma)](1/\sigma - M - 1)/(M+2)^2,$$

which is positive if and only if $\sigma < 1/(M+1)$. Thus, when $\sigma < 1/(M+1)$, entry is deterred. If $\sigma > 1/(M+1)$, however, $\partial \pi_1^d / \partial c_1 < 0$ so multinational firm 1 deviates with transfer of its state-of-the-art technology. Since the local firm acquires the technology c_A/σ, a defection yields

$$\tilde{\pi}_1^d = [a - (M+1)c_A + (M-1)\bar{c}_D + c_A/\sigma]^2/(M+2)^2$$

We find that

$$\pi^D > \tilde{\pi}_1^d$$

if and only if

$$a + (M+1)(M+1-1/\sigma)c_A - (M^2+M+1)\bar{c}_D > 0. \tag{10}$$

Substituting for $\bar{c}_D$, we can rewrite (10) as

$$(M+1)[1/\sigma-(1+M)]\{a-[(M+1)/\sigma-M]c_A\}+(M^2+M+1)(M+2)\sqrt{e} > 0.$$

This condition is more likely to hold when a is small, c_A is high and e is also high.

References

[1] d'Aspremont, C., and A. Jacquemin, 1988, Cooperative and noncooperative R&D in duopoly with spillovers, *American Economic Review* 78, 1137-1137.

[2] Diwan, I, and D. Rodrik, 1991, Patents, appropriate technology, and North-South trade, *Quarterly Journal of Economics* 30, 27-47.

[3] Ethier, W. J., and J. R. Markusen, 1996, Multinational firms, technology diffusion and trade, *Journal of International Economics* 41, 1-28.

[4] Fosfuri, A., 2000, Patent protection, imitation and the mode of technology transfer, *International Journal of Industrial Organization* 18, D1129-1149.

[5] Fosfuri, A., M. Motta, and T. Ronde, 2001, Foreign direct investment and spillovers though workers' mobility, *Journal of International Economics* 53, 205-222.

[6] Gallini, N. T., 1992, Patent policy and costly imitation, *RAND Journal of Economics* 23, 52-63.

[7] Ghosh, A., H. Morita and X. Nguyen, 2018, Technology spillovers, intellectual property rights, and export-platform FDI, *Journal of Economic Behavior and Organization* 151, 171-190.

[8] Glass, A. J., and K. Saggi, 2002, Multinational firms and technology transfer, *Scandinavian Journal of Economics* 104, 495-503.

[9] Kohpaiboon, A., 2006, Foreign direct investment and technology spillover: a cross-industry analysis of Thai manufacturing, *World Development* 34, 541-556.

[10] Lee, Y. J. and E. Mansfield, 1996, Intellectual property protection and U.S. foreign direct investment, *Review of Economics and Statistics* 78, 1-9.

[11] Liu, Z., 2002, Foreign direct investment and technology spillover: evidence from China, *Journal of Comparative Economics* 30, 579-602.

[12] Managi, S., and S. M. Bwalya, 2010, Foreign direct investment and technology spillovers in sub-Saharan Africa, *Applied Economics Letters* 17, 605-608.

[13] Mansfield, E., and A. Romeo, 1980, Technology transfer to overseas subsidiaries by US.-based firms, *Quarterly Journal of Economics* 95, 737-750.

[14] Rockett, K, 1990, The quality of licensed technology, *International Journal of Industrial Organization* 8, 559-574.

[15] Teece, D. J., 1977, Technology transfer by multinational firms: the resource cost of transferring technological know-how, *Economic Journal* 87,242-261.