MANAGEMENT SCIENCE
Vol. 56, No. 3, March 2010, pp. 536–552
ISSN 0025-1909 | EISSN 1526-5501 | 10 | 5603 | 0536

DOI 10.1287/mnsc.1090.1111

Component-Based Technology Transfer in the Presence of Potential Imitators

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Technology transfer to low-cost locations offers global firms an opportunity to reduce their variable costs involved in serving emerging markets. However, such moves may also make imitation by local competitors easier. As a consequence, technology transfer may create competition in the local market. We introduce component-based technology transfer for the global firm as a means to deter or accommodate the imitators' entry, recognizing that components may differ in technological complexity. By choosing a subset of components to transfer, the global firm's decision has an impact not only on the imitators' fixed entry costs, but also on postentry competition based on variable costs. Our research identifies two different types of deterrence strategies—the *barrier-erecting strategy* and the *market-grabbing strategy*. In the former deterrence strategy, the global firm retains enough component technology in the home country to make the potential imitator's fixed entry costs so high that it is not worthwhile entering. In the latter deterrence strategy, the global firm transfers enough component technology to the emerging market, reducing the global firm's variable cost to make the potential imitator's revenues so low that it is not worthwhile entering. Which deterrence strategy the global firm should employ depends on the degree to which geographical proximity reduces imitation costs and the degree of differentiation between the local firm's and the global firm's products. Some other interesting and counterintuitive results arise. For example, it may benefit a global firm to transfer less technology for products with a higher emerging market potential.

Key words: technology transfer; cost-saving potential; technology imitation; sourcing
History: Received June 28, 2006; accepted October 14, 2009, by Aleda Roth, operations and supply chain management. Published online in *Articles in Advance* February 12, 2010.

1. Introduction

Emerging economies such as Brazil, Russia, India, and China are attractive for their untapped markets, as well as for their ample supply of cheap labor. To exploit both these opportunities, global firms are establishing local operations in these emerging markets. This requires sometimes costly transfer of technology from the firm's home base to the new location. However, such moves to emerging countries may backfire because they facilitate imitators' market entry by enabling them to copy the global firm's product. As a result, by establishing local operations in emerging markets, firms may create their own competitors.

We observe that companies in different industries follow different technology transfer strategies. For example, foreign automakers in China aim to localize the production of cars and spare parts to leverage low labor and factor costs to the highest extent (Boston Consulting Group 2008). Luxury goods companies such as Prada and Valentino produce their exclusive lines completely in developing countries such as Turkey and Eastern Europe to leverage low labor costs (*Wall Street Journal* 2005). Netafim, an Israel-based irrigation system firm, on the other hand, carefully keeps the production of key components at home, with the intent to deter copying by a local imitator. Similarly, a large equipment manufacturer designs and develops hardware in China but produces the related software abroad to reduce the possibility of a technology leak (Dietz et al. 2005).

Technology transfer and competitive strategies are thus intertwined: A global firm can influence the competitive landscape to some extent through controlled technology-transfer strategies. We introduce component-based technology transfer for the global firm as a means to deter or accommodate the imitators' entry, recognizing that components may differ in technological complexity. By choosing a subset of components to transfer, the global firm's decision has an impact not only on the imitators' fixed entry costs, but also on the postentry competition based on variable costs. How much and which component technology to transfer, and whether to fend off or to tolerate imitators in the emerging economy, must be determined simultaneously.

Several factors determine technology-transfer strategies in the presence of potential imitation, including variable-cost-saving potential, fixed transfer and imitation costs, market potential, and product differentiation. These factors have been well recognized in the academic literature and business press and can be synthesized as follows:

- *Variable Cost-Saving Potential.* Labor requirements are determining factors of variable cost reduction. The cost savings from a cheap labor supply can be significant and is typically a key motivation to transfer operations to emerging economies. For example, in the safety-equipment industry, in 2007 the hourly labor rate was 16 U.S. dollars in the United States, and 1.5 U.S. dollars in China, which, for example, leads to a 35% net reduction in the variable cost[1] for making a self-contained breathing apparatus by transferring all production.
- *Fixed Costs of Technology Transfer.* Standardized technologies are readily moveable. However, the technology of making complex components, such as the coil suspension spring in automobiles, can be very costly and time consuming to replicate and transfer (Bergmann et al. 2004). General Motors (GM), for example, has had great difficulty in transferring manufacturing practices between divisions (*Business Week* 1992). The fixed costs associated with technology transfer have been acknowledged in the academic literature (Galbraith 1990, von Hippel 1994, Szulanski 1996). These costs can be high compared with the revenue that can be earned in emerging markets, particularly when product life cycles are short. Technical know-how, especially in its tacit form, is often the impediment to transfer (Polanyi 1967). The implicit and uncodifiable characteristics of tacit knowledge make it difficult to codify, manipulate, and move, even within an organization (Reed and DeFillippi 1990). Teece (1977), for instance, finds that the transmission and assimilation of unembedded technical know-how accounts, on average, for 19% of transfer costs. Previous studies have suggested that the technology-transfer cost depends on characteristics such as its complexity (Simon 1962, Schaefer 1987). Furthermore, the amount and complexity level of the technical know-how required to make components can be very different from one component to another (Banker et al. 1990). All these studies indicate that the fixed costs of technology transfer are determined by the complexity of the components that are transferred. Typically, the more complex the technology required to make a component, the higher are the fixed costs associated with transferring that component.
- *Fixed Costs of Technology Imitation.* Imitators incur high costs when developing product specifications, constructing prototypes, and inventing around intellectual property (IP) protections or developing a noninfringing imitation (Mansfield et al. 1981, Gallini 1992). Because the underlying phenomena of technology transfer and imitation are similar, regardless of whether the replication occurs within or across firms' boundaries (Polanyi 1967, Winter 1987), technology transfer triggers imitation processes. Keeping all else equal, the higher the complexity of a component, the higher are the fixed costs for local firms to imitate the component. To reveal the interplay between technology transfer of a global firm and imitation of local firms, we elaborate more on the process of imitation. In some cases, successful imitation hinges on replicating the manufacturing processes or tacit know-how of skilled labor. Imitators do this by hiring away employees from the source company. Given that hiring employees from other companies is easier when companies are located in the same region, the localization of manufacturing operations makes imitation easier (Das 1987). As a result, the geographical (physical) separation of operations successfully limits the employees' mobility, which is a major channel of technology spread to rivals in these industries (Glass and Saggi 2002). In some other cases, fewer key technologies are contained in manufacturing processes or labor skills, but more proprietary information resides in the physical forms of the products, such as shapes, configuration, and components' interfaces (Varady et al. 1997). In such situations, imitation is possible using reverse engineering, imitators enter the market no matter where the manufacturing is located (Samuelson and Scotchmer 2002), and separating production geographically will not raise entry barriers to imitators.

The imitation of GM technology by local Asian manufacturers is a classic example and has caused a series of lawsuits (Tao and Ho 2005). Chery, a state-owned Chinese company, introduced the Chery QQ, which is very similar in appearance to GM's Chevrolet Spark, built in China. GM's investigation

[1] Obviously, besides the labor costs, other costs (e.g., transportation, tariffs, and taxes) need to be taken into account when exploiting labor-rate differences between countries, but in general these added costs are less than the savings in labor costs.

results showed that the two vehicles "shared remarkably identical body structure, exterior design, interior design, and key components." This striking case illustrates that geographical proximity helped technology imitation. Codifying complex technology for the purpose of replication and transfer will significantly reduce, in such situations, the outsiders' efforts to interpret and copy it (Kogut and Zander 1992, Zander and Kogut 1995). In contrast, technology transfer in the electronics goods industry has less impact on the vulnerability of the global firm to imitation. The products of companies such as Apple and LG are easily imitable by reverse engineering because of their focus on exterior and other tangible features. Ainol, a Chinese portable media player producer, markets the "Chinese iPhone and iPod" and cell phones similar to the LG Chocolate (Koeppel 2007).

In general, transferring a technology to a local market reduces the costs of local firms' imitation of the transferred technology. We refer to the relative reduction in imitation costs due to the increased proximity of local firms to the technology as the *imitation sensitivity to location*, and provide a formal definition in §3. Clearly, the imitation sensitivity introduced by technology transfer for products that are predominantly reverse engineered is low because it matters little where the production takes place (in the home or in the emerging country). For products that are imitated by luring away employees, imitation sensitivity is high; technology transfer to the emerging country can significantly reduce the imitators' fixed costs to enter the market.

• *The Market Potential.* The local market potential plays a major role in a firm's technology-transfer decisions. The market potential determines the revenues that can be earned by entering the local market. Some products, such as consumer electronics, have enormous market potential because of population dynamics and changes in purchasing power in the emerging markets. Large potential makes it attractive not only for the global firm, but also for potential imitators, to enter the market. For some products that have relatively small potential, it may still be attractive for the global firm to have some operations in the emerging economy because it is less likely that the transfer will invite local imitators.

• *Product Differentiation.* The Chery QQ example illustrates why GM is concerned about imitation. Because of its (striking) physical resemblance, GM's Chevrolet Spark competes head on with the Chery QQ. Local imitators' products, however, need not to be perfect substitutes. Local brands often differentiate themselves from global brands along intangible dimensions by, for example, their domesticity and adapting features to local culture (Interbrand 2005, *New York Times* 2009). Therefore, the degree of differentiation between the original and imitated products will have an impact on the intensity of competition and, hence, a financial impact on both the global firm and local imitators in the case of the imitators' entry. This suggests that the degree of differentiation will determine the level of a global firm's concern about possible entry by imitators as a consequence of technology transfer.

When trying to understand how these factors lead to the observed alternative technology-transfer strategies, the following research questions naturally emerge: (1) Which and how much technology to transfer? (2) How does the presence of a potential imitator impact the technology-transfer strategy? (3) When should a global firm accommodate an imitator's entry? (4) When and how should a global firm impede a potential imitator? The answers are not obvious.

To address these questions, we develop a stylized model in the following setting: A global firm owns the technology to make a product, and a local firm in an emerging market can access the market only if it imitates the global firm's technology. The firm's strategic interactions are modeled as the sequential stages of transfer of technology by the global firm and potential imitation by the local firm (Das 1987), followed by quantity decisions by the two firms. The model analysis allows us to formulate a theoretically grounded answer to the questions listed above.

We find that the global firm is able to deter a potential imitator's entry (so that the global firm remains a monopolist) only when the market potential is not too large. Interestingly, it is not always in the global firm's best interest to deter imitation. In some cases, it is more profitable for the global firm to accommodate and share the market with the imitator even if deterrence is possible. However, deterrence is preferred to accommodation at a lower market potential than in the above cases. We find that there exist two types of deterrence strategies: (1) a *barrier-erecting* strategy, in which the global firm keeps enough technology in the home country such that the high entry (imitation) cost prevents the imitator from entering; and (2) a *market-grabbing* strategy, in which the global firm transfers enough technology to improve its variable-cost competitiveness such that the low remaining market share prevents the imitator from entering. We derive conditions under which each of the two deterrence strategies arises in equilibrium and is preferred to the accommodation strategy. Imitation sensitivity and product differentiation level are the main determinants for selecting the appropriate deterrence strategy; high imitation sensitivity and high differentiation make the barrier-erecting strategy more attractive. Our model provides a rationale for technology-transfer strategies observed in different industries.

The remainder of this paper is structured as follows. We review related literature in §2. We introduce the model and the game setup in §3. We solve and interpret the global firm's optimal strategy, considering that the components are heterogeneous in technological complexity in §4. The model is then extended to the case in which the local firm's and the global firm's products are horizontally differentiated in §5. In §6, we discuss a number of other extensions to our base model, the detailed analysis of which is provided in Online Appendix EC.1. In §7, we conclude with managerial implications, limitations, and directions for future research. We provide proofs in Online Appendix EC. 2 and extensions in Online Appendices EC.1 and EC. 2 (available in the e-companion).[2]

2. Related Literature

The economics of technology imitation has been studied in the industrial organization literature. The models of a firm endowed with a technology entering a foreign market have focused on comparing the fixed costs incurred under the different alternatives. For example, researchers study entry-mode choices such as exporting, FDI, or licensing in the presence of imitation (e.g., Ethier and Markusen 1996), technology-level choices (e.g., Pepall and Richards 1994, Pepall 1997), or both choices (e.g., Fosfuri 2000). These decisions have an impact on the imitators' fixed imitation costs. The main conclusion from this stream of research is that the size of the imitation cost determines whether or not an entry-deterrence strategy is preferred by the first mover. The models on incumbents deterring later entrants in the same market include using product quality as an instrument to preempt potential entry (e.g., Hung and Schmitt 1992, Donnenfeld and Weber 1995, Lutz 1997), offering a large product line (e.g., Schmalensee 1978, Brander and Eaton 1984, Bonanno 1987), investing in excess capacity (e.g., Dixit 1980, Maskin 1999), or signaling payoff-relevant information (e.g., Milgrom and Roberts 1982). In our paper, entry deterrence is achieved by either raising entrants' entry costs or reducing their postentry competition payoffs. In addition, to our knowledge, all the research to date examines firms' strategic interaction at the product level. From our observations, component-based transfer is another useful "strategic" instrument. This new instrument has an impact on both the fixed imitation cost and firms' postentry competition based on variable costs that jointly determine the deterrence strategy. In many entry-deterrence models, as reviewed in Nelson and Winter (1982), knowledge transfer within the firm across different geographical locations is assumed to be costless. Therefore, the connection between technology transfer and imitation costs is usually ignored.

Technology imitation is also studied in the strategic management literature. Technology replication is an effective strategy to capture new market opportunities (Winter and Szulanski 2001). High-complexity technology resists both imitation and transfer (Polanyi 1967, Nelson and Winter 1982). Hence, a paradox faced by these firms is identified: Efforts by a firm to replicate its technology enhance the potential for imitation (Kogut and Zander 1992). This literature stream provides a useful framework for our problem: A firm that replicates and transfers technology must factor in the consequences of imitation, and transferring complex technology presents both a high transfer cost and a high imitation risk. In this literature, replication and imitation are connected, but the decision of the rival to imitate knowledge is usually exogenously given (e.g., Rivkin 2000, 2001). Studying how firms conduct research and development (R&D) in emerging economies with weak IP protection, Zhao (2006) shows that firms find it valuable to conduct R&D activities in the countries that possess a growing pool of low-cost human capital by later integrating with complementary technologies held within the firm in other locations. Similarly, geographical separation of operations limits the leakage of manufacturing technology, and, hence, component-based technology transfer naturally emerges as an alternative strategic instrument for firms to use in emerging countries with weak IP protection.

In the operations management literature, researchers study manufacturing strategies and material flow in a multiple-country setting. Focus to date has been on the factor-cost differences and untapped markets as drivers of global manufacturing (e.g., Kogut 1985, DuBois et al. 1993). Researchers also study the organization of global manufacturing networks by minimizing the total production and transportation costs (e.g., Flaherty 1986, Cohen and Lee 1989). Other relevant work in the context of international operations management is well reviewed in Roth et al. (1997) and Prasad and Babbar (2000). China, as a prime target for direct foreign investment as well as a major player in global manufacturing, is emerging as a uniquely interesting location for research. Opportunities and challenges for China-based research are discussed by Zhao et al. (2006, 2007), highlighting issues such as logistics, supply chain management, quality management, and new product development. However, researchers have assumed that technology can be duplicated at no cost, and imitation aspects have

[2] An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

remained largely unexplored. Relevant work in the literature on international technology diffusion is well reviewed in Keller (2004). Despite the relevance of potential imitation as a consequence of technology diffusion, we have found no research that has studied how these factors are linked, and in turn how alternate transfer strategies perform.

3. The Model

We introduce our assumptions concerning the firms, products, technology, market demand, decision set, and cost structures in §3.1. The game setup and equilibrium conditions are described in §3.2.

3.1. Model Setup

3.1.1. Players, Markets, and Products. We consider two firms: A "global" firm with its current operations in a "home" country, and a "local" imitator in a foreign country with an emerging economy. The global firm has developed in the home country a set of "component technologies." Each component technology delivers a component, and all components are then assembled into a final product. For expositional purposes, we consider only one market for the final product, the emerging market. The global firm has no operations in the emerging economy before any component technology is transferred.[3] The global firm considers transferring technology to the emerging economy to serve the local market. There is a local firm in the emerging economy, but it has no component technology to manufacture the product. To enter the emerging market, thus, the local firm must first imitate all component technologies, either from local operations or from home operations of the global firm.

3.1.2. Demand. We assume that the demand function is linear in the emerging market. In the case of a monopoly, the market is cleared at price $P^G(q) = \xi - q$ if the global firm sets an output level q. We refer to ξ as the "market potential," which is the highest price that the market is willing to pay for the product. By definition, $\xi > 0$ and is common knowledge to all players. In the case of a duopoly, we assume that firms compete in quantities, when the global firm produces q^G and the local firm produces q^L, the market-clearing price is given by $P(q^G, q^L) = \xi - q^G - q^L$. In §5, we relax this homogeneous-product assumption and study how (horizontal) differentiation changes the obtained insights.

[3] Note that hereafter we use "technology transfer" and "component-based technology-transfer" interchangeably.

3.1.3. Component Technology and Associated Costs. The global firm can decide where to produce components (either in the home country or in the emerging country). In the case in which it decides to produce some components in the emerging market, technology transfer is required before local production can take place. The global firm transports the components made by its home operations to its local operations and assembles the final product with the locally made components for its demand in the local market. We now discuss in detail the global and local firm's variable and fixed costs as a function of the former's technology-transfer decision.

The Local Firm's Variable Production Costs. The variable production costs in the emerging country are lower than those in the home country. Without loss of generality, we normalize the local firm's variable cost to zero.

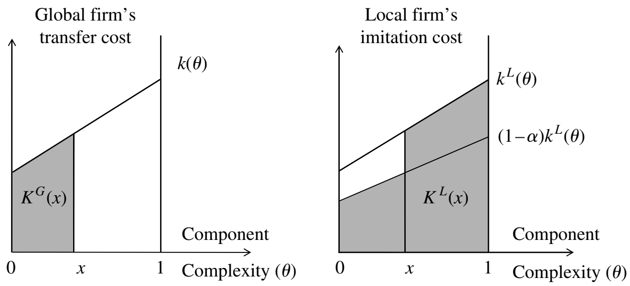
The Global Firm's Variable Production Costs. The global firm has a cost disadvantage of $c > 0$ when transferring no technology, and it achieves parity with the local firm when transferring all technology. We model the set of components that makes up the product as a continuum with a total volume normalized to 1. We label these components by means of an index of complexity, θ, with a range $[0, 1]$. The complexity of components is increasing in θ. We assume that *all* components have identical cost-saving potential. Assuming that a fraction, x, of the components is transferred to the emerging economy, the global firm's variable cost has two components: the production cost of the fraction, x, of components transferred and the production cost of the fraction, $1 - x$, remaining in its home operations. For the sake of simplicity, we suppress the costs of shipping components between the two markets. Because all components are homogeneous in variable-cost-saving potential in the base model, the variable cost after transferring fraction x becomes

$$c(x) = c \times (1 - x). \tag{1}$$

When all manufacturing remains at home, $x = 0$, the global firm's variable cost is given by $c(0) = c$. When all components are transferred, $x = 1$, the global firm's variable cost is $c(1) = 0$ and, hence, is at par with the local firm.

The Global Firm's Technology-Transfer Costs. The fixed transfer cost of each component may be different. Transferring complex technology presents a high transfer cost. The total fixed transfer cost is then the sum of the transfer cost of each transferred component. We assume that the transfer cost of the component range $[\theta, \theta + \mathrm{d}\theta]$ is $k(\theta)\mathrm{d}\theta$, where $k(\theta) \doteq k_0 + k_1\theta$. This cost structure acknowledges heterogeneity in the complexity of components. Because all components have identical variable-cost savings, any technology

Figure 1 Global Firm's Technology-Transfer Cost and Local Firm's Imitation Cost as a Function of Component Complexity, θ



Notes. The shaded area determines the transfer cost (on the left panel) and imitation cost (on the right panel) when transferring the component range $[0, x]$. The nonshaded area under $k^L(\theta)$ of the imitation cost represents the imitation cost savings due to the technology transfer.

transfer should include the components with the lowest fixed costs. That is, only the component range $[0, x]$ should be considered if the firm considers transferring a fraction, x, of the components. The total costs of transferring components $[0, x]$ are given by $K^G(x) = \int_0^x k(\theta)\,d\theta$, which is a quadratic function in x. The left panel of Figure 1 illustrates the global firm's transfer cost as a function of component complexity θ, where the shaded area under the curve $k(\theta)$ equals the transfer cost $K^G(x)$. The firm incurs no transfer cost if there is no transfer, i.e., $K^G(0) = 0$; it incurs cost k^G if there is full transfer, i.e., $k^G \doteq K^G(1)$. The more technology the firm transfers, the higher the fixed costs are, i.e., $(d/dx)K^G(x) > 0$; the transfer cost of the marginal component x is increasing in x, i.e., $(d^2/dx^2)K^G(x) > 0$.

The Local Firm's Imitation Costs. To imitate the technology for making the product, the imitator undertakes an investment. If no technology is transferred, the imitator incurs k^L costs to imitate *all* technology from the global firm's home operations. The parameter, k^L, hence captures the imitator's imitation capability. Spillovers of technology to imitators are possible only if they possess sufficient "absorptive capacity" (Cohen and Levinthal 1990). Limited absorptive capacity can possibly arise from lack of prior related technology or lack of template (Rivkin 2001).[4] This determines the imitator's efforts k^L to invest in order to replicate the technology of the global firm. A lower k^L means a higher imitation capability. Because the underlying processes of technology transfer and imitation share similar features, we assume that the index of component complexity, θ, determines the imitation costs in a similar way as it determines the transfer costs: $k^L(\theta) = (k^L/k^G)k(\theta)$, where $k^L = \int_0^1 k^L(\theta)\,d\theta$ is the total imitation cost when there is no technology transfer. With this modeling choice, the shapes of $k^L(\theta)$ and $k(\theta)$ are similar. Recall from §1 that for some products, geographical proximity of operations to local firms facilitates the imitation process because local firms can hire away employees from the global firms. Because of the different imitation mechanisms (hiring away employees versus reverse engineering) illustrated with the examples in §1, we define the *imitation sensitivity* as the fraction of the reduction in imitation costs due to the transfer of a product or component. We assume that for the component range $[\theta, \theta + d\theta]$ that is transferred, the imitation costs are reduced from $k^L(\theta)d\theta$ to $(1-\alpha)k^L(\theta)d\theta$, where $\alpha \in [0, 1]$ is the imitation sensitivity factor. The parameter α captures how sensitive the entrant's imitation costs are with respect to technology transfer. It allows us to determine the imitator's fixed imitation cost as a function of the global firm's transfer decision x. The right panel of Figure 1 illustrates the imitation cost as a function of component complexity θ, where the shaded area is the imitation cost $K^L(x)$ if the global firm transfers the components of range $[0, x]$, i.e.,

$$K^L(x) = (1-\alpha)\int_0^x k^L(\theta)\,d\theta + \int_x^1 k^L(\theta)\,d\theta. \qquad (2)$$

That is, the imitation costs of the transferred components (range $[0, x]$) are reduced by a fraction α, whereas the imitator incurs the full imitation costs for the remaining components of range $[x, 1]$. In other words, the imitation cost reduction for any partial technology transfer, $x \in [0, 1)$, is $\alpha \int_0^x k^L(\theta)\,d\theta$; with full transfer, $x = 1$, the imitator's fixed costs are reduced by αk^L.

3.2. Game Setup

Now we discuss the structure of the game played by the global firm and the imitator.

3.2.1. The Decisions. The decisions by the global firm and the imitator relating to transfer, imitation, and manufacturing are as follows.

The Global Firm. The global firm's decisions include (i) the fraction of components to transfer to the emerging market, characterized by $x \in [0, 1]$; and (ii) an output level, $q^G \in [0, \xi]$.

The Local Firm. The imitator can potentially enter by imitating the transferred technology from the global firm's local operations, and the rest from its home operations. The imitator's decisions are (i) whether to enter, denoted by $y = NE$ or E ("NE" denotes no entry, "E" denotes entry); and (ii) an output level, $q^L \in [0, \xi]$.

3.2.2. The Game. We model the decisions of the two firms as a sequential process and consider three stages: technology transfer, imitation, followed by a quantity (Cournot) competition. In Stage I, the global

[4] Would-be copycats must rely on search heuristics or on learning, not on algorithmic "solutions," to match the performance of superior firms (Rivkin 2000). Empirical work by Levin et al. (1987) quantitatively studies such deterrence to imitation.

firm moves first by determining the technology-transfer amount, $x \in [0, 1]$. In Stage II, the potential imitator observes the global firm's technology-transfer decision, x, and decides whether to enter the (local) market or not, $y \in \{E, NE\}$. In Stage III, the firms observe each other's decision, and either the global firm behaves as a monopolist and sets an output level $q(x) \in [0, \xi]$, or, if the prospective imitator enters, the two firms enter a quantity competition by setting output levels, $q^G(x) \in [0, \xi]$ and $q^L(x) \in [0, \xi]$, respectively, contingent on the transfer x. With this model setup, we capture that the global firm's decision to transfer technology is irreversible. In technology matters, the global firm is clearly a leader.

The firms' corresponding Stage III profits are then

$$\pi^G(x, y) = \begin{cases} \hat{\pi}^M(q(x); x) & y = NE, \\ \hat{\pi}^G(q^G(x), q^L(x); x) & y = E \end{cases} \tag{3}$$

and

$$\pi^L(x, y) = \begin{cases} 0 & y = NE, \\ \hat{\pi}^L(q^L(x), q^G(x); x) & y = E, \end{cases} \tag{4}$$

where $\hat{\pi}^M(q; x)$ is the global firm's monopoly profit given quantity q and the technology-transfer decision x, and $\hat{\pi}^i(q^i, q^{-i}; x)$ is firm i's duopoly profit given its own quantity q^i, its competitor's quantity q^{-i}, and the technology-transfer decision x. $q^i(x)$ for $i \in \{L, G\}$ is firm i's duopoly quantity: $q^G(x) = \arg\max_{q^G} \hat{\pi}^G(q^G, q^L(x); x)$ and $q^L(x) = \arg\max_{q^L} \hat{\pi}^L(q^G(x), q^L; x)$. $q^M(x)$ is the global firm's monopoly quantity: $q^M(x) = \arg\max_{q^G} \hat{\pi}^M(q; x)$. Both exclude fixed costs. We hereafter refer to the Stage III profit $\pi^i(x, y)$ as the *emerging market profit* of firm $i \in \{G, L\}$ after entering the emerging market.

The imitator's best response $y^*(x)$ at Stage II is then given by $y^*(x) \in \arg\max_{y \in \{NE, E\}} \Pi^L(x, y)$, and the global firm's subgame-perfect-equilibrium strategy x^* at Stage I is given by $x^* \in \arg\max_{x \in [0,1]} \Pi^G(x, y^*(x))$, where $\Pi^i(x, y) = \pi^i(x, y) - K^i(x)$ is referred to as the *net profit* of firm $i \in \{G, L\}$, the emerging market profit π^i net of the fixed entry cost K^i.

The equilibrium analysis of the model provides insights into how the global firm's technology-transfer decision depends on the imitator's strategic reaction and the technology, market, and cost structures. If the imitator chooses to enter, it competes for a share in the emerging market. Confronting this imitator, the global firm must assess deterrence strategies (the firm is a monopoly) or accommodation strategies (the firm and the competitor coexist in the market) by controlling the amount of components to transfer. We summarize the notation in Table 1.

Table 1 Summary of Notations Used

Parameters	Meanings
Model primitives	
ξ	Emerging marketing potential
α	Imitation sensitivity to location
c	Variable cost of the global firm in the home country
k^G (k^L)	Cost to transfer (imitate) all technology from the home market
b	Product substitutability factor
Derived parameters	
x^m	Monopoly optimal (or base) transfer amount
x^d	Duopoly optimal transfer amount
x^l, x^h	Boundaries of no-entry region $x^l \le x^h$
Decision variables	
x	Global firm's transfer amount decision $x \in [0, 1]$
y	Imitator's entry decision $y \in \{E, NE\}$
q^i	Production quantity of firm i
Payoffs	
Π^i	Net profit of firm i in the emerging market
π^i	Emerging market profit of firm i

4. Model Analysis

In this section, we analyze the equilibrium outcome of the base model. We report only the results for the technology-transfer decision of the global firm in the sense that some, but not all, technology is transferred, i.e., $x \in (0, 1)$. We consider the situations in which the equilibrium entry decision of the local firm will be not to enter when the global firm does not transfer any technology, i.e., the cost to imitate all technology from the home market is high and prevents entry (see Online Appendix EC.1(f) for detailed expressions for the bound on k^L). In §4.1, we explain some useful preliminary results. In §4.2, we study the equilibrium strategies of the two firms: global and local. We then qualitatively interpret our results using some examples in §4.3.

4.1. Preliminary Results

In this subsection, we analyze two cornerstone technology-transfer strategies based on which intuition will be developed for the equilibrium technology-transfer strategy of our game. The following subsections characterize the (subgame) equilibrium strategies in Stages III and II. The cornerstone technology-transfer strategies are those that maximize the global firm's profits in the case that the firm is a monopolist or a duopolist. The corresponding transfer fraction of components is denoted by x^m and x^d, respectively. These fractions are determined by trading off variable-cost-reduction benefits with fixed transfer costs, i.e., $x^m = \arg\max_{x \in [0,1]} \Pi^G(x, NE)$, and $x^d = \arg\max_{x \in [0,1]} \Pi^G(x, E)$. Because the market must be split between two firms in the presence of a local imitator, it is intuitive that the demand for the global firm as a duopolist is smaller than when it is a monopolist. Hence, it is to be expected that the marginal cost-saving benefits from technology transfer on the lower production volume of a duopolist is lower than the marginal cost-saving benefits from technology transfer of a monopolist, and the latter transfers more technology than the former. This is a direct (volume) effect. However, the cost reduction enjoyed by the global firm as duopolist has an indirect (strategic) effect: It reduces the (Cournot) quantity of the competitor (the local firm) and, hence, increases the additional market volume the global firm can serve, which, in turn, provides an extra incentive to the global firm to transfer more technology. The following proposition shows that technology transfer will always be more for a monopolist than for a duopolist, i.e., in our model, the direct effect dominates the indirect strategic effect.

Proposition 1 (Cornerstone Technology-Transfer Strategies).

(1) *A firm transfers more component technology as a monopolist than a duopolist, i.e.,* $x^m > x^d$. *The monopolist profits with transfer strategy* x^m *are higher than the duopolist profits with transfer strategy* x^d.

(2) *A firm transfers more component technology in both monopoly and duopoly markets when the market potential* ξ *increases, i.e.,* $\partial x^m/\partial \xi > 0$ *and* $\partial x^d/\partial \xi > 0$.

Proposition 1 highlights two key drivers for technology transfer: (1) the presence of a competitor and (2) the market potential. The presence of a competitor impedes the technology transfer and reduces the profits of the global firm.[5] A larger potential market provides greater benefit to the firm from variable-cost reduction. Hence, the fixed transfer cost concern becomes less important, and the firm transfers more technology for products with a higher market potential. In the remainder of the paper, we refer to x^m as the "base" technology-transfer amount, the amount that the global firm would transfer assuming that it will be a monopolist in the local market. We will analyze cases when the equilibrium technology-transfer amount is equal to, or higher and lower than, the base technology-transfer amount.

4.2. Technology Transfer in the Presence of an Imitator

We now study the situation in which a potential imitator can enter the emerging market by imitating the global firm's technology. A Stage III subgame equilibrium analysis is straightforward and given in Lemma EC.1 in Online Appendix EC.2. In the following, we first analyze the imitator's best response $y^*(x)$ in Stage II to a given transfer decision x of the global firm. We then present the global firm's two types of entry-deterrence strategy, followed by the global firm's optimal transfer strategy x^* in Stage I.

4.2.1. Imitator's Best Response. Assume that the global firm has transferred fraction x of its components to the local market. The imitator enters only when the projected profits exceed the entry cost:

$$y^*(x) = \begin{cases} E & \text{if } \Pi^L(x, E) > 0, \\ NE & \text{otherwise.} \end{cases}$$

We now study a useful property of the local firm's profit in the case that it enters.

Lemma 1. *The imitator's net profit,* $\Pi^L(x, E)$, *in the case of entry is convex in the transfer amount,* x.

The imitator's net profit is convex in the transfer amount x because its emerging market profit π^L is convex, whereas its imitation cost K^L is concave in x. The concavity of the imitation cost, or the convexity of the imitation-cost reduction $\alpha \int_0^x k^L(\theta)\,\mathrm{d}\theta$, is because of the increasing imitation-cost reduction of transferring the marginal component x. The fact that the imitator's emerging market profit π^L is decreasing, but at a decreasing rate, in the transfer amount x or the global firm's variable-cost reduction, stems from the downward-sloping demand function.[6] Lemma 1 highlights a key property that will be important for determining the equilibrium of our game. An important consequence of the convexity of the imitator's net profit is that the global firm can influence the competitive landscape by controlling the amount of technology transfer. Entry is not attractive for the local firm when the global firm transfers neither too much technology nor too little. We denote such a no-entry region by $[x^l, x^h]$. The boundaries, x^l and x^h, are both a function of market potential ξ and determined by $\Pi^L(x, E) = 0$. We then have Proposition 2 on the imitator's entry decision.

Proposition 2 (Imitator's Entry Decision). *The imitator's entry decision is affected by the market potential* (ξ) *and the amount of technology* (x) *transferred by the global firm. Specifically, the imitator will*

(1) *not enter the market if two conditions hold:*

(a) *the market potential is sufficient small, and*

(b) *the global firm transfers a medium amount of component technology;*

(2) *enter the market, otherwise.*

[5] Proposition 1 compares the monopoly case with the duopoly case. The result extends to oligopoly. In Online Appendix EC.1(c), we allow multiple imitators and obtain the same findings (see Proposition EC.3). In addition, it can easily be shown that if the global firm has a sufficient cost advantage with respect to the entrant, the indirect strategic effect may dominate the direct effect and the global firm will transfer more technology in a duopoly case than in a monopoly case. In our case, however, the local firm enjoys a cost advantage, which is a salient feature of emerging markets.

[6] See Lemma EC.1 in Online Appendix EC.2.

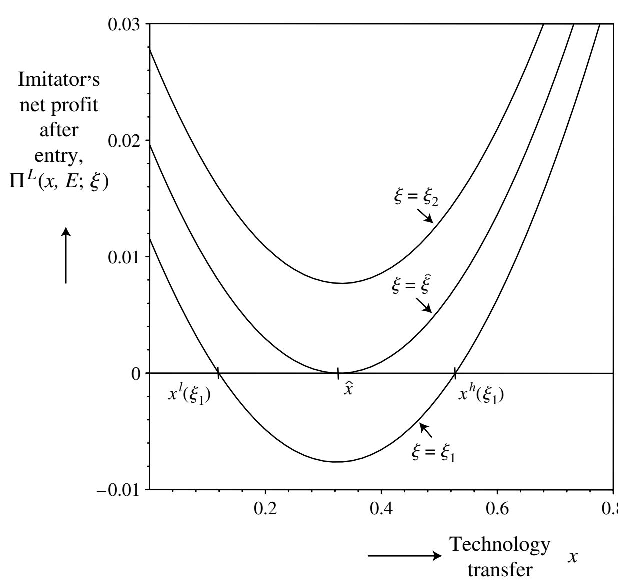
Formally, there exists a $\hat{\xi}$ such that

$$y^*(x) = \begin{cases} NE & \text{if } \xi \le \hat{\xi} \text{ and } x \in [x^l, x^h], \\ E & \text{otherwise.} \end{cases}$$

In addition, the no-entry region shrinks as the market potential increases, i.e., $\partial x^l/\partial \xi > 0$ and $\partial x^h/\partial \xi < 0$ for $\xi \le \hat{\xi}$.

Proposition 2 underscores the importance of the market potential. It is intuitive and can easily be shown that the net profit $\Pi^L(x, E)$ increases with the market potential ξ. That is, the no-entry region $[x^l, x^h]$ shrinks as the market potential increases, i.e., $\partial x^l/\partial \xi > 0$ and $\partial x^h/\partial \xi < 0$, as illustrated in Figure 2. Hence, there exists a critical market potential $\hat{\xi}$, such that for any market potential below this critical level, $\xi < \hat{\xi}$, the no-entry region $[x^l, x^h]$ is nonempty. In these cases, the imitator enters when it reaps a high emerging market profit, π^L, or incurs a low entry cost, K^L, such that the net profit, $\Pi^L(x, E)$, becomes positive. The former happens when the global firm transfers a low amount ($x \in [0, x^l)$), such that the imitator faces a weak competitor who has a strong cost disadvantage with respect to the imitator. The latter takes place when the global firm transfers a high amount ($x \in (x^h, 1]$), such that the imitator incurs low imitation costs due to the presence of a large amount of technology at the global firm's local operations. At the critical potential, $\hat{\xi}$, the no-entry region $[x^l, x^h]$ shrinks to a single point, $\hat{x} \doteq x^l = x^h$. For any larger market potential, $\xi > \hat{\xi}$, the no-entry region disappears, i.e., the imitator obtains positive profit for any possible transfer amount x. The global firm cannot prevent entry with a controlled transfer of technology.

Figure 2 **Illustration of Local Firm's Net Profits After Entry (E), $\Pi^L(x, E; \xi)$, as a Function of Global Firm's Technology Transfer Strategy, x, for Different Values of Market Potential, ξ: $\xi_1 < \hat{\xi} < \xi_2$**



Note. We use $c = 0.3$, $\alpha = 0.5$, $k_0 = 0$, $k_1 = 0.4$, and $k^L/k^G = 1.75$.

4.2.2. Global Firm's Entry-Deterrence Strategies. The imitator's best response in Proposition 2 indicates that the global firm can use technology transfer to deter imitation. The medium region, $x \in [x^l, x^h]$, if it exists, is one that guarantees the imitator will not enter. If the base technology-transfer amount, x^m, falls into this region, the global firm reaps the highest profits and deters the imitator's entry. This is ideal for the global firm: Ignoring any competitive effects is then justified and leads to the highest (monopoly) profits. However, it is possible that the base transfer amount, x^m, does *not* fall into this no-entry or deterrence region. In other words, the base transfer strategy, x^m, does not always result in a monopoly, and hence is not necessarily the equilibrium of our game. If the global firm wants to deter a potential imitator, it has to forgo some benefits in variable-cost reduction (low transfer costs) by transferring a smaller (larger) fraction of components than the base transfer amount. This aspect is stated in the following proposition:

Proposition 3 (Global Firm's Entry-Deterrence Strategies). *In the presence of an imitator, the global firm's base technology-transfer strategy*

(1) *deters potential entry of a local imitator when the market potential is low,*

(2)(a) *is too low to deter potential entry of a local imitator when the imitation sensitivity is low and the market potential is high,*

(b) *is too high to deter potential entry of a local imitator when the imitation sensitivity is high and the market potential is high.*

Formally, there exist $\hat{\alpha}$, $\underline{\xi}$, and $\hat{\xi}$ such that

$$x^m \in \begin{cases} [x^l, x^h] & \text{if } 0 < \xi \le \underline{\xi}, \\ [0, x^l) & \text{if } \underline{\xi} < \xi \le \hat{\xi} \text{ and } \alpha < \hat{\alpha}, \\ (x^h, 1] & \text{if } \underline{\xi} < \xi \le \hat{\xi} \text{ and } \alpha \ge \hat{\alpha}. \end{cases}$$

Here, $\hat{\alpha}$ is an imitation sensitivity level for which $\hat{x} = x^m$ when $\xi = \hat{\xi}$, and $\underline{\xi}$ is the market potential for which $x^l = x^m$ when $\alpha < \hat{\alpha}$, or $x^h = x^m$ when $\alpha \ge \hat{\alpha}$.

When the market potential is low (i.e., $\xi \le \underline{\xi}$), the base transfer amount, x^m, lies inside the no-entry region, irrespective of imitation sensitivity. In other words, the base transfer amount deters a potential entrant. In these situations, a global firm can safely transfer technology to an emerging economy by trading off the revenues resulting from variable-cost savings against the incurred fixed costs, ignoring any competitive interaction. However, when the market potential is high (i.e., $\xi > \underline{\xi}$), if the global firm transferred the base transfer amount, it would attract an imitator and, hence, the Stage III competition equilibrium would be a duopoly. If the global firm would like to remain a monopolist in Stage III, the global firm must transfer *more* than the base transfer amount (i.e., at least x^l) in the case of low imitation sensitivity (i.e., $\alpha < \hat{\alpha}$). This is captured in statement (2(a)) in Proposition 3. Interestingly, with high imitation sensitivity (i.e., $\alpha \geq \hat{\alpha}$), the situation is different. For high market potential, if the global firm wants to remain a monopolist, it must transfer *less* than the base transfer amount (i.e., at most x^h). This is captured in statement (2(b)).

The difference in the deterrence strategies illustrates the key role that imitation sensitivity, α, plays. The intuition is as follows. With low imitation sensitivity, the location of the operations does not greatly influence the imitator's fixed entry costs. Hence, the only way to make entry unattractive is to make the imitator's profit after entry low. This can be done through a fierce cost competition by transferring a large proportion of components and making the global firm's variable cost very low. We refer to this as the *market-grabbing strategy*. This strategy does not work with a high imitation sensitivity, in which case it would reduce the imitator's fixed cost and open the prospect of entry. With high imitation sensitivity, the strategy, then, is to create a high entry barrier by transferring less than the base transfer amount such that the imitator has to face high fixed entry costs. We refer to this as the *barrier-erecting strategy*.

Consider now the strategic behavior of the global firm at its technology-transfer stage (Stage I). Proposition 3 suggests that there exist two types of deterrence strategy by intentionally transferring either more or less than the base transfer amount, and the global firm employs the better one depending on the level of imitation sensitivity, α. Both deterrence strategies come with their associated costs: In the former, the firm incurs high transfer costs; in the latter, the firm forgoes some cost-saving benefits. Therefore, when the global firm has an option to deter (i.e., the no-entry region $[x^l, x^h]$ is nonempty), it may want to forgo the deterrence option and instead accommodate the imitator's entry if it gains higher duopoly profits.

So far, we have identified four technology-transfer strategies, x^m, x^d, x^l, and x^h, that may or may not be equilibria of our game, x^*. Next, we discuss when each strategy is an equilibrium.

4.2.3. Global Firm's Optimal Technology-Transfer Strategies. We now characterize the Stage I optimal technology-transfer strategies, i.e., whether the global firm should deter or accommodate the imitator's entry and, in the case of entry, which deterrence strategy the global firm should employ. Recall that when the global firm has an option to deter, it may prefer accommodation to deterrence. We first define $\bar{\xi}$ to be the smallest market potential in these cases. Hence, below $\bar{\xi}$, the global firm prefers to deter; above $\bar{\xi}$, the firm prefers to accommodate.[7] If there are no such cases (i.e., if the firm always prefers to deter as long as the no-entry region is nonempty), $\bar{\xi}$ becomes the critical market potential $\hat{\xi}$ above which the imitator always enters (Proposition 2). Formally, $\bar{\xi}$ is determined as follows:

$$\bar{\xi} = \begin{cases} \min\{\xi \in [0, \hat{\xi}): \Pi^G(x^d, E) \geq \max\limits_{x \in [x^l, x^h]} \Pi^G(x, NE)\} \\ \qquad \text{if } \Pi^G(\hat{x}^d, E) \geq \Pi^G(\hat{x}, NE), \\ \hat{\xi} \quad \text{otherwise,} \end{cases} \tag{5}$$

where $\hat{x}$ is the no-entry region (a single point) at the critical potential $\xi = \hat{\xi}$, and $\hat{x}^d$ is the duopoly optimal transfer amount at $\xi = \hat{\xi}$. Because the no-entry region becomes empty for any market potential above $\hat{\xi}$, it is clear that $\bar{\xi} \leq \hat{\xi}$. Recall that $\underline{\xi}$ is the market potential for which $x^l = x^m$ for low sensitivity $\alpha < \hat{\alpha}$, or $x^h = x^m$ for high sensitivity $\alpha \geq \hat{\alpha}$ (see Proposition 3). It is easy to see that $\underline{\xi} \leq \bar{\xi}$, because at $\xi = \underline{\xi}$, the global firm should always deter because it obtains the maximum possible profit by transferring x^m.

Now, we state our main proposition:

Proposition 4 (Global Firm's Optimal Transfer Strategies).

(1) *If the market potential is low, the global firm deters the imitator's entry by transferring the base* (*monopoly*) *amount.*

(2) *If the market potential is medium, it deters by*

(a) *employing a market-grabbing strategy and transferring more than the base amount when imitation sensitivity is low,*

(b) *employing a barrier-erecting strategy and transferring less than the base amount when imitation sensitivity is high.*

(3) *If the market potential is high, it accommodates by transferring the duopoly amount.*

Formally,

$$x^* = \begin{cases} x^m & \text{if } 0 < \xi \leq \underline{\xi}, \\ x^l \ (> x^m) & \text{if } \underline{\xi} < \xi \leq \bar{\xi} \text{ and } \alpha < \hat{\alpha}, \\ x^h \ (< x^m) & \text{if } \underline{\xi} < \xi \leq \bar{\xi} \text{ and } \alpha \geq \hat{\alpha}, \\ x^d & \text{if } \xi > \bar{\xi}. \end{cases}$$

[7] With this definition, we assume that for $\xi > \bar{\xi}$ the global firm's monopoly profits constrained over $[x^l, x^h]$ do remain lower than the global firm's duopoly profits. Proving analytically that this is always true is complex because of the fourth-order polynomials. In all our numerical experiments, we have observed that this is true.

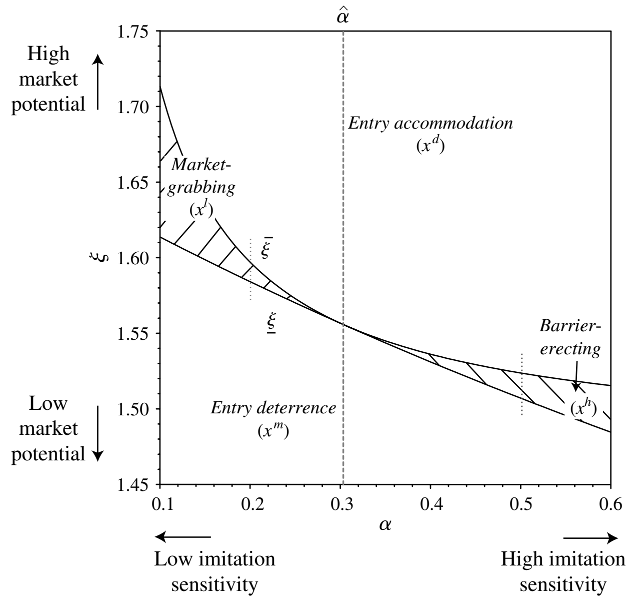
Proposition 4 reveals the important interplay between market potential and transfer strategy. For products with a low market potential ($\xi \le \underline{\xi}$), the global firm can transfer as if it were a monopolist. Recall from §3 that imitation sensitivity α determines the imitation cost reduction due to technology transfer (i.e., k^L if no technology is transferred versus $k^L(1-\alpha)$ if all technology is transferred). In the case of high imitation sensitivity ($\alpha \ge \hat{\alpha}$), the technology transfer decision significantly impacts the local firm's imitation cost. For products with a high market potential ($\underline{\xi} < \xi \le \bar{\xi}$), the global firm is likely to invite an entrant if it were to transfer the base amount, x^m. Thus, the global firm transfers *less* technology, x^h, than the base amount to deter the entrant. The monopolist essentially erects an entry barrier. The global firm, however, loses variable-cost competitiveness in the emerging market because less than the (monopoly) optimal amount of technology is transferred. Based on our conversations with executives at Mine Safety Appliances Company (MSA), a world-leading company in safety equipment, in the context of technology transfer to Asia of microbolometer thermal detectors (sensors) and other electric components in thermal-imaging cameras, this strategy has been followed. Global companies thus knowingly keep some key technologies at home to make imitation difficult.[8]

In the case of low sensitivity ($\alpha < \hat{\alpha}$), the imitation costs are not significantly impacted by the transfer amount. Contrary to the high imitation sensitivity case, for products with a high market potential ($\underline{\xi} < \xi \le \bar{\xi}$), the entry threat forces the global firm to transfer *more*, x^l, than the base amount to deter the entrant. The reason for this increase in transfer is that transferring technology does not significantly reduce imitation costs. Therefore, an alternative means of reducing a potential imitator's emerging market profits is to manufacture products at a very low cost. Thus, the global firm incurs high transfer costs, but gains variable-cost competitiveness, in the emerging market.

When the market potential increases to a level, $\bar{\xi}$, the deterrence strategy becomes less attractive either because of the forgone cost-saving benefits in the low imitation sensitivity case or because of the high transfer costs in the high imitation sensitivity case. The global firm therefore forgoes the deterrence option and accommodates the imitator by transferring the duopoly amount x^d.

[8] This is based on a pilot study carried out at MSA's plants in the United States and Asia, and conversations with the vice president of operations, Paul Uhler, and regional operations executives Mr. Digiovanni and Mr. Hsu, when the first author was serving on their Global Manufacturing Council from 2004 to 2005.

Figure 3 Optimal Competitive Strategy Regions Defined by Imitation Sensitivity α and Market Potential ξ



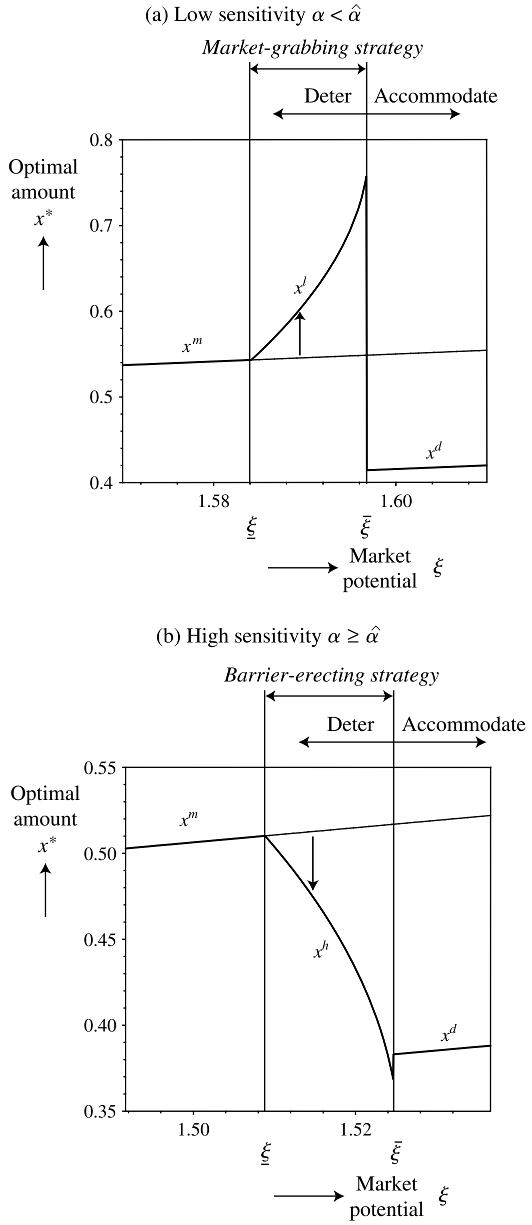
Notes. The equilibrium technology-transfer strategy is indicated in parentheses. We use the same parameter set as in Figure 2. In Figure 4, we will plot the optimal technology-transfer amounts on the two short vertical dashed lines on the figure, i.e., $\alpha = 0.2$ and $\alpha = 0.5$.

Proposition 4 is illustrated in Figure 3, which depicts the Stage I technology-transfer decision of the global firm in the imitation-sensitivity-market-potential space. Below the critical market potential $\underline{\xi}$ (Proposition 3), the global firm can deter imitation by transferring the base technology. Above the critical market potential $\bar{\xi}$ (Equation (5)), the global firm prefers accommodation, and in the medium region $[\underline{\xi}, \bar{\xi}]$, the strategy employed by the global firm to deter imitation depends on the imitation sensitivity level, as discussed above. For low imitation sensitivity, a market-grabbing strategy emerges. For high sensitivity, a barrier-erecting strategy emerges.

Now we illustrate in Figure 4 how the global firm's optimal technology-transfer amount x^* changes as a function of the market potential ξ in each imitation sensitivity case. We selected two levels of imitation sensitivity, α; on the left panel, α is less than the critical imitation sensitivity, $\hat{\alpha}$, and on the right panel, α is higher than the critical imitation sensitivity. All other parameters are the same as in Figure 3, where the selected levels of α are plotted as vertical lines.

It is interesting to note that the change in technology transfer is not monotonic. When the market potential is low ($\xi \le \underline{\xi}$), more technology (x^m) is transferred for products with a higher market potential, i.e., $\partial x^m / \partial \xi > 0$ (see Proposition 1). When imitation sensitivity is low (left panel), for products with a medium market potential ($\underline{\xi} < \xi \le \bar{\xi}$), in which the global firm deploys a market-grabbing strategy to

Figure 4 **Illustration of Market-Grabbing Strategy (a) and Barrier-Erecting Strategy (b)**



Notes. Over $[\underline{\xi}, \bar{\xi}]$, the transfer amount is more (less) than the base transfer amount, x^m, for low (high) sensitivity. We use the same parameter set as in Figure 2. We evaluate the optimal technology-transfer amounts on the two short vertical dashed lines plotted on Figure 3, i.e., panel (a) for $\alpha = 0.2$ and panel (b) for $\alpha = 0.5$.

keep out the entrant, more technology has to be transferred for products with a higher market potential to be more cost competitive, i.e., $\partial x^l/\partial\xi > 0$. As mentioned above, only for products with a high market potential ($\xi > \bar{\xi}$) does the global firm suffer too great a loss if it tries to keep the entrant out of the market. In these cases, the global firm scales back the technology-transfer amount from x^l to x^d to accommodate the imitator's entry.

When imitation sensitivity is high (right panel), it becomes less intuitive to determine how the market potential impacts the technology-transfer strategy. Only for products with a low market potential ($\xi < \underline{\xi}$) must more technology be transferred for products with a higher market potential. For products with a medium potential ($\underline{\xi} < \xi \leq \bar{\xi}$), in which the global firm deploys the barrier-erecting strategy to keep out the entrant, the global firm must *withhold more* technology for products with a higher market potential to increase the barriers and fend off the entrant, i.e., $\partial x^h/\partial\xi < 0$. This reduction may become so strong that the global firm transfers less than a duopolist in order to remain a monopolist. For products with a high market potential ($\xi > \bar{\xi}$), this strategy becomes too expensive, and the global firm is relieved from the withholding strategy by transferring the duopoly technology amount. We believe that this situation was experienced by General Electric (GE) in transferring locomotive technology to China. Because of the high market potential of the Chinese locomotive market, GE knew that local firms were likely to enter the market. By transferring much of its technology to China and lowering its variable cost, GE sought gains in market share (as well as the ability to source parts back to its existing markets).[9]

4.2.4. Sensitivity with Respect to Other Parameters. So far, we have focused on market potential as the main determinant of a technology-transfer strategy. We now discuss how the factors cost difference, c, total transfer cost, k^G, and total imitation cost, k^L, change the technology-transfer strategy.[10] First, our numerical study shows that the global firm is more likely to accommodate entry when the cost difference, c, increases. Intuitively, it is more difficult to deter the entry of an imitator who has a stronger cost advantage. Second, we observe that with a higher transfer cost k^G, the global firm is more likely to accommodate entry when imitation sensitivity is low, but to deter entry when imitation sensitivity is high. In the low-sensitivity case, the global firm deters the imitator's entry by transferring more, and therefore incurring higher transfer costs. When the transfer cost increases, the deterrence strategy becomes far more costly. The opposite occurs in the high-sensitivity case because the global firm deters imitation by transferring less. The impact of the imitation cost, k^L, is likewise intuitive. Changes of k^L can be regarded as a measure of changes in the imitator's imitation capability, or changes in the IP protection strength in the

[9] This is based on our discussions with the president of GE MONEY, Mr. Fujimore, on March 8, 2007.

[10] Recall that k^G is the cost of transferring all technology, $\int_0^1 k(\theta)\,d\theta$, and k^L is the cost of imitation when no technology is transferred, $\int_0^1 k^L(\theta)\,d\theta$.

emerging country. It can be shown that the global firm is more likely to deter entry when the imitation cost, k^L, increases. In the next subsection, we illustrate our findings by discussing stylized observations concerning the technology-transfer strategies of firms in different industries.

4.3. Interpreting Observed Firms' Strategies

In this subsection, we discuss qualitatively how our insights may be used to explain technology-transfer strategies in different situations. Recall that our main parameters are imitation sensitivity, market potential, cost-saving potential, and transfer costs. We are particularly interested in how much technology the firm should transfer compared with the base level, x^m, the monopoly-optimal transfer amount that ignores competitive effects, in the case of deterrence. (We note here that our model is highly stylized and should not be used as a decision support tool.) The goal of the interpretation below is to sharpen managers' intuition regarding the proper strategy to employ in a given situation and should be considered as indicative, and only a starting point for strategy crafting.

For firms such as Prada and Apple, separating operations will likely not raise imitators' entry barriers because imitation sensitivity to technology transfer is low. Facing low local demand for its exclusive lines in developing countries such as Turkey and Eastern Europe, Prada transfers nearly all its technology so that its variable cost is reduced to a level similar to that of the local imitator. Imitators thus do not enter because of their low emerging market profit in the case of entry. This behavior supports the market-grabbing strategy. In the case of Apple, however, it is relatively difficult to prevent imitation no matter how much it transfers, because of the high demand in local markets. Apple transfers most of its technology to Asia, and keeps the production of only a few complex components at home to avoid high transfer costs. Thus, Apple forgoes the deterrence option and transfers technology by assuming that it will compete with imitators (such as Ainol).

In contrast, for firms such as Netafim, keeping key technology in the home country works well by raising imitators' entry costs. In other words, imitation sensitivity to technology transfer is high. Hence, in the case of low demand in the local market, the imitators' entry can be easily deterred by using the barrier-erecting strategy. Netafim remains a dominant player in emerging markets. In the case of GM, however, it is difficult to prevent imitation because of high demand in the local markets. GM forgoes the deterrence option, and transfers technology by assuming that it will compete with imitators (such as Chery).

The global firms' optimal strategies are sensitive to the other parameters, as indicated in the previous section. First, a larger cost difference (or labor cost savings) c makes it harder to deter an imitator's entry. Hence, in both low- and high-sensitivity cases, Prada and Netafim will more likely accommodate entry for products with higher labor content. Second, with a higher transfer cost k^G, in the low-sensitivity case, Prada is likely to accommodate entry for complex products with expensive technology transfer. In the high-sensitivity case, however, the opposite occurs and GM is likely to deter entry. Finally, Apple and GM are likely to deter entry in regions in which imitators have lower imitation capability (i.e., higher imitation costs k^L).

5. Extension: Competition in a Differentiated Duopoly

In our base model, we assumed Cournot quantity competition between the global and local firm. However, in many cases, the products of the global and local firms are differentiated because of their different brand names, local reputation, and distribution channels. In this section, we model the impact of product differentiation by extending our Cournot competition model to a differentiated duopoly model (Singh and Vives 1984). In the case of a monopoly, the market is cleared at price $P^G(q) = \xi - q$ if the global firm sets an output level q. In the case of a duopoly, when the global firm produces q^G and the local firm produces q^L, the market-clearing prices are given by

$$P^G(q^G, q^L) = \xi - q^G - bq^L \quad \text{and} \qquad (6)$$
$$P^L(q^G, q^L) = \xi - q^L - bq^G,$$

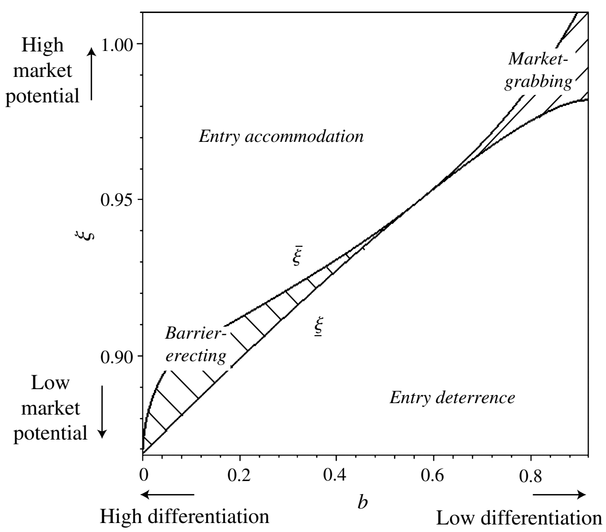
where $b \in [0, 1]$. b is a measure of the degree of differentiation between the local firm's and global firm's profit. When $b = 1$, the two firms' products are not differentiated, i.e., it reduces to the base model discussed in §3. When $b = 0$, the global and local firms' products are so differentiated that they become independent of each other. Any value of $b \in (0, 1)$ captures a degree of product differentiation. We again assume that ξ and b are common knowledge to both players. Even though with Equation (6) firms compete in quantities, Singh and Vives (1984) demonstrate that this model can be reinterpreted as a model of horizontally differentiated Bertrand price competition (by inverting the price–quantity relationships). We obtain the following results.

Proposition 5 (Differentiated Products).

(1) *The qualitative insights obtained in* §3 *remain true when the products are substitutable* (*i.e., when* $b > 0$).

(2) *As the degree of differentiation increases such that they become independent of each other* (*i.e.,* $b \to 0+$), *the market-grabbing strategy region,* $[0, \hat{\alpha})$, *disappears* (*i.e.,* $\lim_{b\to 0+} \hat{\alpha} = 0$), *and the region in which the firm strategically transfers technology,* $(\underline{\xi}, \bar{\xi})$, *disappears too, i.e.,* $\lim_{b\to 0+} \underline{\xi} = \lim_{b\to 0+} \bar{\xi}$.

Figure 5 Illustration of Different Strategies When the Product Differentiation Decreases, i.e., b Increases



Note. We use $c = 0.7$, $\alpha = 0.4$, $k_0 = 0$, $k_1 = 0.4$, and $k^L/k^G = 1.1$.

Statement (1) in Proposition 5 confirms that when the products are differentiated, all our previously obtained insights about the technology-transfer strategies remain valid. Proposition 5(2) states that as the products become so differentiated that they do not impact each other's market share anymore (i.e., b tends to 0), (a) the market-grabbing strategy loses its appeal first (i.e., $\hat{\alpha}$ tends to 0) and (b) the region in which the firm uses technology transfer strategically to deter entry disappears (i.e., $\underline{\xi}$ tends to $\bar{\xi}$). Statement (b) is obvious because when the imitator's product is unrelated to the global firm's, the global firm does not need to strategically transfer technology. Statement (a) is more interesting. It is because a market-grabbing strategy relies on the global firm's fierce cost competition, which in turn depends on how effectively the global firm can influence the local firm's market share. When the local and global firms' products are too differentiated, this strategy becomes ineffective. Figure 5 illustrates Proposition 5. The parameters are such that for undifferentiated products ($b = 1$), market-grabbing is the deterrence strategy of choice (i.e., $\alpha < \hat{\alpha}$). Observe from Figure 5 that as the local and global firms' products become more differentiated (i.e., b decreases), the market-grabbing strategy disappears and is replaced by the barrier-erecting strategy. This happens when the critical sensitivity, $\hat{\alpha}$, which varies with b, drops below α, which is kept constant in the figure. However, as product differentiation further increases (i.e., b decreases), the region $[\underline{\xi}, \bar{\xi}]$ also shrinks, i.e., the global firm uses technology transfer strategically over a smaller range of market potential.

6. Other Extensions

In Online Appendix EC.1, we discuss a number of other extensions to our base model. We summarize the main findings in this section.

6.1. Heterogeneity in Variable-Cost-Saving Potential

In our base model, we assume that the variable-cost savings are homogeneous for all components. In practice, however, because of different labor content, not all components in a product have the same cost-saving potential when the operations are transferred to emerging countries. For example, the potential cost savings for automobile components are different: Some have negligible cost savings (e.g., windshields and fuel tanks), and others can have a cost savings of over 70% (e.g., alternator pulley and compressor valve) by sourcing from China or India (Bergmann et al. 2004). In that case, a natural tension may be created: The components with the highest variable-cost savings are also the components with the highest fixed transfer cost. Then, the question becomes whether to transfer the readily movable component technologies (i.e., the "low hanging fruit"), or to transfer the complex component technologies that achieve significant variable-cost savings at high fixed costs. We develop an immediate extension of our base model, in which the variable-cost savings of the component range indexed by $[\theta, \theta + \mathrm{d}\theta]$ are $(c_0 + c_1\theta)\mathrm{d}\theta$. In other words, the least-complex components (low θ) yield the lowest cost savings. Depending on the relative heterogeneity of fixed costs versus variable costs (k_0/k_1 versus c_0/c_1), as discussed in Online Appendix EC.1(b)), the global firm either first transfers components with low complexity (i.e., transfer strategies are of the form $[0, x]$) or first transfers components with high complexity (i.e., transfer strategies are of the form $[x, 1]$). In either case, we find that our qualitative insights of the base model remain valid.

6.2. Multiple Imitators

In our base model, we assume that only one local firm enters the market. It may well be that multiple local firms consider imitating the global firm's product and enter the market. We address this situation in Online Appendix EC.1(c) by considering $n \geq 1$ identical local firms that enter the market. We find that the presence of multiple imitators makes the deterrence strategy more attractive.

6.3. Selling in the Home and the Emerging Markets

In the base model, we also assume that the global firm does not source from the emerging market to its home market, and the two firms compete in the emerging market only. We relax this assumption by allowing the global firm to source for its home market in Online Appendix EC.1(d). We find that a larger home market potential makes the deterrence strategy more attractive when imitation sensitivity is low, in which case the firm deters imitation by transferring more than the base transfer amount, but less attractive when sensitivity is high, in which case the firm deters imitation by transferring less than the base transfer amount.

6.4. Uncertain Market Potential

Finally, in our base model, we also assume that the emerging market potential, ξ, is common knowledge. We relax this assumption in Online Appendix EC.1(e) by considering that the global firm does not have perfect knowledge of the emerging market potential, but the local firm does. We find that the global firm's information disadvantage leads to a larger accommodation region.

7. Conclusions

We have studied imitative competition, motivated by problems faced by several companies in diverse industries who consider transferring technology to emerging markets for manufacturing. For some products, the imitator's fixed costs are very sensitive with respect to the location of the global firm's operations. As the transfer of technology facilitates unwanted imitation, firms must balance the need to lower manufacturing costs against the need to prevent technology from unintentionally leaking to other firms. Component-based technology transfer has a simultaneous impact on fixed entry costs and postentry competition. Imitation sensitivity, market potential, and degree of product differentiation are critical factors that determine whether the global firm should deter or accommodate an imitator's entry, and if it should deter, how should it do so? These factors jointly determine the emerging market profit the imitator can obtain in the case of entry and, hence, the level of difficulty in deterring the imitator's entry. The interplay among these factors makes this research especially interesting. Our paper derives the following important managerial insights.

7.1. Managerial Insights

First, in some cases when the market potential is high, even though the global firm has the ability to deter an imitator's entry, it prefers accommodating and sharing the market with the imitator. When the market potential is low, however, the global firm can safely transfer technology, ignoring any potential competition because the market will not be sufficiently profitable to overcome the imitator's fixed entry cost. Second, when deterrence is preferred to accommodation, the global firm deters imitation by transferring less (a barrier-erecting strategy), but also in some cases more (a market-grabbing strategy), than the base technology-transfer amount. Which strategy is more effective depends on the level of a combination of imitation sensitivity and product differentiation. Keeping the imitator's entry cost high with a barrier-erecting strategy is preferable when imitation sensitivity is high, whereas significantly reducing its variable costs and therefore competing aggressively to reduce the imitator's emerging market profit with a market-grabbing strategy is preferable when imitation sensitivity is low. The critical imitation sensitivity level that separates the two strategies depends on the degree of product differentiation: The more direct the competition with imitated products, the more attractive the market-grabbing strategy becomes relative to the barrier-erecting strategy. Third, there are compelling reasons for transferring a lower amount of technology for products with a higher market potential. When switching from a market-grabbing deterrence strategy to an accommodation strategy, the global firm transfers less technology because of lower cost-reduction benefits on a lower market share. With a barrier-erecting strategy, the global firm withholds more technology for products with a higher market potential to raise entry costs and deter the imitator's entry.

7.2. Limitations and Future Research

Even though our insights are robust with respect to a number of model assumptions (multiple local firms, heterogeneous variable-cost savings in addition to heterogeneous transfer costs, and, finally, allowing the local firm to export to the global firm's home market), we conclude our paper with some limitations and ideas for future research. Our comparative statics have revealed some properties of how the optimal technology-transfer strategy depends on the market potential. For example, in some cases it is optimal to transfer less technology as the market potential increases. This finding has some interesting dynamic implications when markets are growing over time (a feature that is not considered in our model): It may be difficult to withdraw technology over time to implement a barrier-erecting strategy, especially after the technology (or a part of it) has been imitated. Considering dynamic technology-transfer strategies is an interesting avenue for further research. We have also assumed that the heterogeneity of the fixed transfer costs and the variable-cost savings can be captured by means of a linear function of a single-dimensional complexity index. As a result, the fixed transfer costs and variable-cost savings for a given transfer strategy are quadratic (i.e., the integral over the complexity index range that is transferred). Our model has allowed us to capture the first-order effects when linking the fixed transfer costs and variable-cost savings. This may be a good assumption when the products have a modular design and an assembly type of production process. However, for products with different architectures and production processes, more-complicated cost structures need to be considered. It may be that higher-order terms of the cost functions become important. More detailed studies that link the product architecture and production process structure to the variable costs, transfer and imitation costs, and their impact on technology-transfer strategies are interesting avenues for further research. In addition, we assume that the product differentiation is exogenously given. In some situations, it can be an endogenous decision of the local firm. Finally, we do not consider that producing more components at the same location may save more production (e.g., setup) costs. Studying more-realistic and more-detailed technology-transfer strategies using quantitative decision models is another interesting avenue for further research.

8. Electronic Companion

An electronic companion to this paper is available as part of the online version that can be found at http://mansci.journal.informs.org/.

Acknowledgments

The authors thank the department editor, Aleda Roth, the associate editor, three anonymous reviewers, and Kinshuk Jerath for constructive comments on earlier versions of this paper, which helped improve the paper significantly. The authors gratefully thank Mine Safety Appliances Company, Vice President Paul Uhler, and members of the Global Manufacturing Council of MSA for motivating this research and for providing helpful suggestions. The authors also acknowledge the financial support granted by the Carnegie Bosch Institute at Carnegie Mellon University.

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