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R&D offshoring and technology learning in emerging economies: Firm-level evidence from the ICT industry

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Abstract

This paper studies the impact of the R&D offshoring of multinational enterprises on the firms in host emerging economies. We develop a two-stage non-cooperative game to analyze the strategic interaction between multinational and host country enterprises engaged in R&D investment. An empirical analysis of 12,309 manufacturing firms in the ICT industry in China shows that R&D offshoring has a positive effect on the intensity of the R&D of host country firms. However, the magnitude of the impact depends on both the technological and geographical distance between the multinational and host country firms. The policy implications of these findings are that the governments of host country should be cautious about allowing advanced multinational R&D investment in under-developed sectors, but they should encourage such investment in developed sectors; and that local governments should be involved in R&D policy making because the positive impact of multinational R&D offshoring diminishes as the geographical distance between the multinational and host country firms increases.

Keywords: R&D; offshoring; spillover; emerging economies
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1. Introduction

Geographical boundaries have become increasingly blurred with regard to the R&D activities of multinational enterprises (MNEs).[5] Rising R&D costs, the increasing risk and complexity of technological development, and intense competition in domestic and global markets have compelled firms to locate their R&D activities outside the borders of their home countries (Stembridge, 2007). The primary destinations of the R&D offshoring of MNEs appear to be emerging economies[6]. A 2005 survey of 209 MNEs in the United States and Western Europe revealed that about 70 percent of the respondents expected an increase in R&D employment in China in the next three years, and slightly more than 40 percent anticipated an expansion in India (Thursby and Thursby, 2006).

The escalating R&D expansion of MNEs to emerging economies has drawn considerable attention in their home countries. Policy makers in their home countries are worried that R&D offshoring could lead to a loss of crucial intellectual property to overseas competitors (Hemphill, 2005), which would create an immediate threat to their competitive advantage (Lieberman, 2004; Bardhan and Jaffee, 2005). Moreover, the possible shedding of well-paid R&D jobs and the downward pressure on the wages of engineers and research scientists in the home countries could bear serious consequences because their students would be discouraged from pursuing engineering or science careers, which further exacerbates the problem of losing competitive advantage in the long run.

Different from policy makers, managers of MNEs are puzzled by an emerging "networked innovation system" based on their R&D offshoring actions (Engardio, 2006; Bardhan, 2006). The Boston Consulting Group (2005) argued that decisions such as where to locate a new R&D center, what roles to assign it, and how to integrate it into the existing innovation infrastructure

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[5] We use the terms "MNEs" and "foreign firms" interchangeably to refer to firms that operate not only in their home countries but also in foreign countries. We use "domestic firms," "local firms," and "host country firms" interchangeably to refer to firms that operate only in countries where MNEs offshore their R&D.
[6] Emerging economies are defined as "low-income, rapid-growth countries using economic liberalization as their primary engine of growth" (Hoskisson et al. 2000; Arnold and Quelch 1998). China is commonly identified as an emerging economy (Hoskisson et al. 2000).

of the MNE would directly impact the outcome of investments and thus demand systematic attention.

Responding to the concerns and questions about R&D offshoring, researchers have extensively investigated factors that motivate or inhibit R&D offshoring (e.g., Thursby and Thursby, 2006; Ambos, 2005; Kuemmerle, 1999; Le Bas and Sierra, 2002) and the conditions in which R&D offshoring could benefit MNEs and their home countries (e.g., Gersbach and Schmutzler, 2006). In general, researchers have reached a consensus that the prime purposes of MNE R&D offshoring are to seek resources and to exploit existing knowledge developed in the home country. Thursby and Thursby (2006) found that market growth potential and R&D personnel quality are the top two factors that drive MNEs to offshore R&D to emerging economies, while the quality of intellectual property protection inhibits MNE R&D offshoring to these economies. In terms of the impact of MNE R&D offshoring on home countries, Gersbach and Schmutzler (2006) found that it usually increases their welfare.

Beyond the above-mentioned research focusing on MNEs and their home countries, we find few studies that tackle the issue from the perspective of the host countries. This paper fills this gap by investigating the impact of MNE R&D offshoring on the R&D investment of host country firms in emerging economies. We argue that its influence on host countries could have a long-term impact on both the MNEs and their home countries, as it disturbs the equilibrium of R&D investment competition between foreign firms and domestic firms in host countries and forces the domestic firms to respond. That is, since domestic firms have much to learn from their foreign counterparts with regard to R&D activities, they would strengthen their commitment to R&D so that they could compete with the foreign entrants at a more advanced level. Furthermore, MNE R&D investment in host countries increases the R&D capital stock in these countries, manifested as scientific instruments, advanced machinery, and sophisticated facilities. This capital stock could generate a demand for advanced facilities and machinery in the host countries and stimulate the development of related high-tech industries. MNE R&D investment could also create research-oriented jobs, which would motivate host countries to expand their higher education system, train more scientists and engineers, and nurture the development of high caliber human resources. Overall, the effects of MNE R&D offshoring on host countries could affect the competitive edge of both the MNEs and their home countries in the long run. To succeed in overseas markets, the MNEs and the policy makers of their home countries must anticipate the possible reactions of host country firms before they engage in any R&D activity. Otherwise, they could be positioned at a disadvantage in the long run.

Host country governments, particularly those in emerging economies, have endeavored to facilitate technology spillover from foreign direct investment (FDI) (Lieberman, 2004) because they believe successful technology spillover can help domestic firms build indigenous technological capabilities and eventually move up in the value chain. However, evidence has shown that the presence of foreign capital does not guarantee technology spillover. For example, Aitken and Harrison (1999) found that foreign investment negatively affected the productivity of domestically-owned plants in Venezuela because joint ventures gained market share at the expense of domestically-owned firms and forced them to produce less at a higher average cost. Following Cohen and Levinthal (1989)[7], we argue that without its own adequate R&D investment, a domestic firm will face problems of achieving technology spillover and improving its indigenous innovation capabilities, even with an influx of foreign capital. If domestic firms are to succeed in learning technology by developing their own R&D investment, policy makers and business managers in host countries must recognize the contribution of MNE R&D offshoring to R&D investment decisions of the domestic firms.

To explain how MNE R&D offshoring shapes R&D investment decisions of domestic firms, we have developed a two-stage non-cooperative game. In the first stage of the game, an MNE and a domestic firm engage in cost reduction R&D. In the second stage, both firms participate in Cournot competition in a homogeneous product market. The model implies that MNE R&D offshoring could positively affect the R&D investment decision of a domestic firm if it is sufficiently easy for the firm to learn from the MNE. However, the influence from the MNE could become negative if learning becomes difficult.

[7] Cohen and Levinthal (1989) argued that R&D develops a firm's ability to identify, assimilate, and exploit knowledge in the public domain or that generated by its competitors.

Our empirical analysis of 12,309 manufacturing firms in the electronic and telecommunications (ICT) sector in China shows that MNE R&D offshoring has a positive effect on R&D intensity of domestic firms in the ICT industry in China. However, the magnitude of the impact depends on the technological and geographical distance between MNEs and domestic firms. For domestic firms with relatively low technology and management capabilities, their R&D investment is primarily affected by MNEs whose capabilities are inferior to theirs and less affected by the MNEs whose capabilities are superior. By contrast, for domestic firms with relatively high capabilities, their R&D investment decisions are mainly influenced by MNEs whose capabilities are superior to theirs in terms of labor productivity and less affected by the MNEs whose capabilities are inferior. As to geographical distance, we find that the positive effect of R&D investment diminishes as the distance between the MNEs and the domestic firms increases.

The remainder of this paper is organized as follows. Section 2 provides the framework used to explain the rationale behind the R&D investment decisions of domestic firms in response to MNE R&D offshoring. Section 3 presents empirical evidence, Section 4 presents findings and related policy implications, and Section 5 concludes.

2. A Theoretical Framework

2.1 Review of the literature on FDI, technology spillover, and host country firm R&D investment

As reviewed by Crespo and Fontoura (2007), the literature on FDI suggests that positive spillover could occur through five channels: demonstration of foreign enterprises, the mobility of labor, the positive impact of MNE on the export capacity of domestic firms, the competition induced by MNE in the domestic economy and backward and forward linkage with domestic firms[8]. However, a number of studies presented contrasting findings that FDI could negatively affect the productivity of host country firms. For example, using the data of Venezuelan firms, Aitken and Harrison (1999) proposed the market stealing hypothesis to account for negative FDI spillovers. They contested that competition from foreign entrants forces domestic firms to reduce

[8] Technology spillover in FDI literature generally refers to the positive effects of FDI on the productivity of host country firms. A detailed review of the FDI literature can also be found in Blomstrom and Kokko (1998, 2001), Saggi (2002) and Marin and Bell (2006).

their output, which indirectly increases their average production costs. Consequently, the presence of foreign capital lowers the productivity of the domestic firms. In their study of Moroccan firms, Haddad and Harrison (1993) similarly rejected the hypothesis that the presence of foreign firms accelerated the productivity growth of domestic firms. In spite of the rigor of these analyses using plant level data, they received some criticism. Javorcik (2004) argued that studies by Haddad and Harrison (1993) and Aitken and Harrison (1999) failed to find positive FDI spillovers because they focused merely on intra-industry, or horizontal spillovers. Javorcik (2004) measured vertical (inter-industry) spillover in a study of Lithuanian manufacturing firms and found positive productivity spillovers between foreign affiliates and their local suppliers in upstream sectors.

Another stream of research, which emphasized the impact of FDI on the R&D investment of host country firms, provided a different explanation for the empirical finding of negative FDI spillover, which we refer to as the "R&D impact" hypothesis. It is known that the R&D investment of domestic firms not only directly contributes to their productivity growth (Potterie and Lichtenberg, 2001; Basant and Fikkert, 1996) but also indirectly influences their growth by facilitating technology spillover from FDI (Kokko, 1994; Alvarez and Molero, 2005). Therefore, the productivity of domestic firms could be positively affected by FDI if the FDI had a positive effect on domestic R&D investment; otherwise, it would be negatively affected. In fact, the linkage revealed by the "R&D impact" hypothesis is one important component of the effect of FDI on the R&D investment of domestic firms, and then on their productivity growth.

The conclusions of previous theoretical work pertaining to the "R&D impact" hypothesis have been ambiguous. Sanna-Randaccio (2002) studied a two-country, two-firm problem in which each firm decides "the mode of foreign expansion; how much to invest in R&D; and how much to sell in each market." The equilibrium results proved that FDI has an ambiguous effect on domestic R&D. The author argued that the intensity of spillover, the technological characteristics of the firms, and the characteristics of the sector together shape the effect of FDI on domestic R&D. Similarly, Haller (2004) investigated how the modes of entry of MNEs influenced the R&D decision of host country firms. The author found that the entry of a more efficient foreign firm will lead to lower domestic R&D investment but higher total R&D investment in an industry. However, the author ruled out the possibility of spillover from the MNEs to the domestic firms in the theoretical analysis, which is the central argument in this paper.

Empirical studies on the impact of FDI on the R&D investment of domestic firms by and large supported the theoretical propositions. Veugelers and Houte (1990) argued that MNEs in a host country may stimulate the innovative activities of domestic firms because of the potential knowledge spillovers. However, they also emphasized that competition from the MNEs may limit their production scale and thus reduce domestic R&D expenditures. Their empirical analysis pointed to a significant negative effect of MNEs on the R&D expenditures of domestic firms in Belgium. Using industry level data of the United Kingdom, Driffield (2001) examined how the R&D investments of foreign and domestic firms affect the productivity growth of the domestic firms. The author found that the R&D investment of domestic firms has a significant positive effect on their productivity growth but the R&D investment of foreign firms has an insignificant effect. Moreover, the author found that the R&D investment of foreign firms negatively affects the R&D investment of their domestic counterparts.

Different from the above literature, our study focuses on the impact of MNE R&D investment on host country firms in *emerging economies*, whose technological capabilities are generally inferior to those of firms in developed economies. The intensity of MNE technology spillover and the influence of MNE on the R&D intensity of domestic firms could differ in emerging economies, compared with those in advanced countries such as Belgium and the UK. Moreover, economists have generally considered FDI as the flow of homogeneous capital to host countries and studied their overall impact on the R&D investment of domestic firms without differentiating the diverse types of FDI. However, FDI that involves production or service supposedly influences local firms differently from FDI that involves R&D activities. For example, so-called technology-exploiting MNEs might employ mainly local low-skilled workers in their manufacturing plants; in contrast, technology-seeking MNEs may hire primarily highly-educated personnel such as engineers and scientists in their R&D centers[9]. Accordingly, the mechanism and magnitude of technology spillover as well as their impact on the R&D

[9] According to Chung and Alcacer (2002), technology exploiting and technology seeking are two major motives of FDI. The former means that an MNE internalizes its unique capabilities and utilizes them in foreign countries; the latter means that an MNE expands abroad in search of capabilities that are not available in its home country.

investment of local firms in these two types of MNEs might also differ.[10] We view R&D investment of foreign firms in emerging economies as an advanced form of FDI and disentangle its effect on the R&D investment of domestic firms from the overall impact of FDI.

Because of the important distinctions between our research and prior literature, we did not draw on the existing FDI spillover literature, which largely focuses on FDI in general rather than FDI in R&D in particular. Instead, we build a simple model in the next section to develop a theoretical foundation for our analysis. Our intention is not to develop a theory, but to illustrate the underlying economic rationale within the context of this research.

2.2 A Simple Model of foreign and domestic R&D investment

Consider an MNE and a domestic firm that operate in a homogeneous product market in a host country. The decision making process of the two firms is modeled as a two-stage non-cooperative game (with no collusion). In the first stage, they simultaneously engage in cost reduction R&D activities[11]. In the second stage, they participate in a Cournot competition[12].

The marginal cost of production of an MNE is $\hat{c}_1$ before it invests in R&D in the host country. Similarly, the marginal cost of production of a domestic firm is $\hat{c}_2$[13]. In the first stage, the MNE and the domestic firm simultaneously determine their cost-reduction R&D effort x_1 and x_2. In addition to the cost reduction resulting from its own R&D, the domestic firm can reduce its production costs through absorbing R&D spillover from the MNE. As a result, the domestic firm's marginal production cost at the beginning of the second stage is $c_2 = \hat{c}_2 - x_2 - b_2 x_1,\ 0 < b_2 < 1$. b_2 represents how easily the domestic firm can absorb R&D spillover from the MNE; in

[10] In surveys of literature characterizing the mechanisms through which spillover takes place, Blomstrom and Kokko (1998) and Saggi (2002) suggest that the labor mobility effect is one of the channels through which spillover may be realized. The other three channels are the demonstration effect, the competition effect, and the R&D stimulation effect.

[11] We study cost reduction R&D because many MNEs offshore their business to China in order to reduce production cost, though MNEs could offshore R&D for the purpose of new product development as well. Moreover, to some extent, R&D for new product development could be viewed as R&D for cost reduction in a modeling framework (Tirole 1988). Thus, merely considering cost reduction R&D in our model does not limit the generalization of our conclusion.

[12] Cournot competition is a reasonable assumption in our setting because MNEs that invest in China aim to grab a high market share in one of the world's fastest growing market (von Zedtwitz 2004). Studies on the motives of R&D offshoring can be found in Ambos (2005), Le Bas and Sierra (2002), and Kuemmerle (1999).

[13] In the rest of the paper, we use subscripts 1 and 2 to denote the MNE and the domestic firm, respectively.

other words, it represents how easily the domestic firm can learn from the R&D activities of the MNE. Similarly, the MNE can take in local technological expertise as well. The marginal production cost of the MNE at the beginning of the second stage is $c_1 = \hat{c}_1 - x_1 - b_1 x_2$[14]; b_1 represents its capability of exploiting local technological know-how and $0 < b_1 < 1$.

Following D'Aspremont and Jacquemin (1988), we assume the costs of R&D to be quadratic and model them as $\gamma x_1^2/2$ and $\gamma x_2^2/2$ for the MNE and the domestic firm, respectively. We use the same parameter γ for the MNE and the domestic firm because they employ the same pool of resources for their R&D activities (D'Aspremont and Jacquemin, 1988).[15] In the second stage of the game, the two firms engage in a Cournot competition in which each firm determines its production quantity (q_1 for the MNE and q_2 for the domestic firm) conditional on x_1 and x_2. The inverse demand function is modeled as $p = 1 - Q$, where $Q = q_1 + q_2$ and p denote the market clear price. The model is solved using backward induction. In the second stage, the profit of firm i is

(1) $\pi_i = (1-Q)q_i - c_i q_i - \gamma \frac{x_i^2}{2}$, $i = 1, 2$.[16]

Substituting c_i into the profit function yields

(2) $\pi_i = (1-Q)q_i - (\hat{c}_i - x_i - b_i x_j)q_i - \gamma \frac{x_i^2}{2}$, $i, j = 1, 2, j \neq i$.

The Nash-Cournot equilibrium is computed as

(3) $q_i^* = \frac{1 - 2c_i + c_j}{3}$, $i, j = 1, 2, j \neq i$.

We assume no exit option in the game, i.e., $q_i^* > 0$, because we are interested in the relationship between the decision of the MNE and that of the domestic firm. Going back to the first stage, we substitute q_i^* into the profit function and solve for x_i. There is a unique optimal solution for x_i when b_j satisfies

[14] We consider the R&D investment of a domestic firm as the only source of local technological expertise in order to simplify the analysis, though the MNE can exploit local technological expertise in other ways, such as collaboration with local universities and research institutes (Thursby and Thursby 2006).
[15] We do not assume that the MNE is more efficient in R&D than the domestic firm, i.e., $\gamma_1 < \gamma_2$, because it is not clear whether this is the case in the ICT sector in China. Moreover, incorporating this constraint into the model would not change the main findings. To keep it simple, we choose to stay with $\gamma_1 = \gamma_2 = \gamma$.
[16] The fixed cost of production is normalized to zero.

(4) $b_j > 2 - 3\sqrt{\frac{\gamma}{2}}$, $j \neq i$.

The unique optimal x_i satisfies $\frac{\partial \pi_i}{\partial x_i} = 0$, which is equivalent to

(5) $\frac{2}{3}(1 - 2c_i + c_j)(\frac{2}{3} - \frac{1}{3}b_j) - \gamma x_i^* = 0$, $i, j = 1, 2, j \neq i$.

We derive the relationship between x_1 and x_2 by differentiating the left-hand side of equation (5) with respect to x_j:

(6) $\frac{dx_i}{dx_j} = -\frac{\partial^2 \pi_i / \partial x_i \partial x_j}{\partial^2 \pi_i / \partial x_i^2} = \frac{\frac{2}{3}(\frac{2}{3} - \frac{1}{3}b_j)(2b_i - 1)}{-\partial^2 \pi_i / \partial x_i^2}$, $i, j = 1, 2, j \neq i$.

The sign of equation (6) is determined by the nominator, which is positive when $b_i > 1/2$ and negative when $b_i < 1/2$. Combining these conditions with the optimality condition in (4) and assuming $\gamma < 1/2$, we derive the complete relationship between x_1 and x_2. For $i, j = 1, 2$ and $j \neq i$,

(7) $\frac{dx_i}{dx_j} > 0$ when $b_i > \frac{1}{2}$, and

(8) $\frac{dx_i}{dx_j} < 0$ when $2 - 3\sqrt{\frac{\gamma}{2}} < b_i < \frac{1}{2}$.

(7) and (8) imply that the R&D investments of the MNE have a positive effect on the R&D investments of the domestic firm if it is sufficiently easy for the domestic firm to learn from the MNE. However, the R&D investment of the MNE has a negative effect if it is difficult for the domestic firm to learn from the MNE. We examine the rationale behind these results by inspecting how the R&D investments of the MNE affect the output of the domestic firm[17].

(9) $\frac{\partial q_2}{\partial x_1} = \frac{\partial q_2}{\partial c_2}\frac{\partial c_2}{\partial x_1} + \frac{\partial q_2}{\partial c_1}\frac{\partial c_1}{\partial x_1}$.

The first multiplicative expression in equation (9) is always positive and represents a spillover effect: Because the domestic firm absorbs the R&D spillover from the MNE, it is able to reduce its cost and raise its output. The second expression is always negative and represents a

[17] Because $\frac{\partial q_2^*}{\partial x_2}$ is always positive, the sign of $\frac{\partial x_2}{\partial x_1}$ is determined by $\frac{\partial q_2}{\partial x_1}$.

competition effect: Although an increase in the R&D investments of the MNE cuts its own production cost, it indirectly raises the costs of the domestic firm, leading to a decrease in its output. The two processes compete with each other, and the observed result is their net effect.

To summarize, when it is sufficiently easy for the domestic firms to learn from the MNEs, that is, when absorbing R&D spillover from the MNEs is easy, the spillover effect dominates the competition effect, leading to a net positive effect of the MNE R&D offshoring on the R&D investment of the domestic firm. When it is difficult for the domestic firms to learn from the MNEs, the competition effect dominates the spillover effect, leading to a net negative effect of the MNE R&D offshoring. In general, how easily the domestic firms learn from the MNEs determines the net impact of the two competing factors.

3. Empirical Evidence from the Electronic and Telecommunications Sector in China

3.1 Data

We explore empirical evidence using a dataset constructed by the National Bureau of Statistics of China on a yearly basis from 2001 to 2005. The cleaned dataset includes 4,506 firms in the 2001 data, 4,834 in the 2002 data, 5,565 in the 2003 data, and 8,525 in the 2005 data[18], totaling 12,309 manufacturing firms in the two-digit electronic and telecommunication sector (ICT). Each firm is assigned an invariant code in the dataset so that we can match the observations of each firm across the four-year observation period. The dataset contains more than 50 statistical indicators, including firm input, output, R&D expenditures, capital composition, employment, geographical location, the sector in which a firm operates (at four-digit sector level), ownership status, and assets and liabilities.

The ICT industry in China is an excellent example for our empirical research. First, China's ICT sector has developed rapidly in recent years. The main driver of the development of the Chinese ICT sector has been the rapid development of domestic firms and the inflow of foreign

[18] The data cleaning is implemented through deleting the observations with negative industrial output value, employee number, sales volume, industrial added value, and R&D investment value. The data in 2004 are not included in this analysis because of the lack of R&D investment value.

investment to this industry. China's trade volume of ICT products increased from 35 billion US Dollars in 1996 to 180 US Dollars in 2004, with an average annual growth rate of 38 percent (OECD, 2005). China is now the sixth strongest global ICT market. Meng and Li (2002) documented that 47 percent of electronic products manufactured at the end of the 1990's in China were produced by foreign firms or joint ventures. Having transferred their manufacturing branches to China to reduce production costs, a majority of MNEs in the ICT sector imported the critical components normally developed in advanced countries, assembled the products in China, and exported the final products to overseas market.[19] Because of this so-called "processing trade", China became the biggest exporter of ICT goods in the world in 2004 (OECD, 2005; Katsuno, 2005).

Another reason why the ICT industry is an excellent example for this research is the considerable competition and interaction between foreign firms and local competitors in the Chinese ICT industry. In spite of their relatively limited size and technological know-how, Chinese domestic ICT firms are rapidly developing their production, export, and R&D capabilities. After all, they compete effectively with MNEs in various product markets within China, and several of them, active in overseas markets, have even emerged as global players[20].

3.2 Econometric framework

To test how the R&D investment of MNEs affects local firms, we adopt the following general econometric framework in the empirical analysis.

(10) $(R\&D\ intensity\ of\ domestic\ firm)_{ijt} = f\ \{(R\&D\ intensity\ of\ MNEs)_{jt},\ (control\ variables)_{ijt}\}$,

[19] Research by Lemoine and Unal-Kesenci (2004), China's National Bureau of Statistics (2005), and Fung (2005) attributed the recent expansion of China's exports in machinery, electrical equipment, and electronic products, in large part to processing trade and the global division of labor, especially in East Asia.
[20] Examples include Lenovo, which acquired the IBM personal computer business in 2004 and became the world's third largest personal computer producer, TCL, which acquired the television business of Thomson in France in late 2003, and Huawei and ZTE, which are active players in the worldwide telecommunications equipment market.

where i, j, t represent a firm, a four-digit level industry, and time, respectively. The data for the variable of the R&D intensity of a domestic firm and the control variables are at the firm level, but those for R&D intensity of MNEs are at a four-digit industry level.

In this framework, we use the R&D intensity of a domestic firm, i.e., the ratio of R&D expenditures to sales value, as the dependent variable. The average R&D intensity of foreign firms at the four-digit industry sector level enters the right-hand side of the function as a key independent variable. Since the R&D investment decision of a firm is influenced by not only its foreign competitors but also many other factors such as the strategy and financial status of the firm and competition in the sector, we include these factors as control variables in the regression. We discuss the control variables in detail in Section 3.2.2.

The theoretical model in Section 2 implies that how the R&D investment of MNEs in a host country impacts the R&D decision of domestic firms depends on the ease of learning in the domestic firms, i.e., how difficult it is for spillover to take place. The difficulty of testing the propositions lies in measuring the ease of learning in the domestic firms and constructing the key independent variables. We discuss the measurement issue and our approach of constructing the key independent variable in Section 3.2.1.

3.2.1 Measurement of the ease of learning and the construction of MNE R&D intensity

Kaiser (2002) reviewed several different methodologies of constructing knowledge spillover variables. These include measuring the technological distance between firms by the patent activities (Jaffe, 1986) and share of scientists in a firm (Adams, 1990), and measuring the Euclidean distance of firm characteristics (Inkmann and Pohlmeier, 1995). Ornaghi (2006) measured the ease of spillover by grouping firms according to their size, R&D expenditures, and geographical location.

In this paper, we measure the ease of learning of a domestic firm using both the technological and geographical distance between the subsidiary company of an MNE in China and local firms. We use labor productivity to construct technological distance since we do not have firm-level data of patent applications and employed scientists in our dataset. Moreover, although we possess data about size and R&D expenditures of the subsidiaries of MNEs, we hesitate to use them as indicators of the technology level of the foreign firms because this information represents only the characteristics of their subsidiaries in China, rather than their overall technology capability. Labor productivity, defined as added value divided by number of employees, represents the technology and management skills of a manufacturing firm in general.

To test the effect of technological distance on the relationship between the R&D intensity of MNEs and domestic firms, we construct three variables—R&D intensity of same-group MNEs, R&D intensity of higher-level-group MNEs, and R&D intensity of lower-level-group MNEs—and include them as key independent variables in our analysis. We follow Ornaghi (2006) to divide the dataset into five subsets (groups) according to the average labor productivity of all firms during the observation period. Each of the groups contains one-fifth of the firms in the dataset[21]. Suppose a domestic firm is classified in the group with the lowest labor productivity[22]. Then the average R&D intensity of the foreign firms in the same lowest labor productivity group and in the same four-digit sector of the domestic firm is taken as the value of the variable R&D intensity of same-group MNEs for this domestic firm. Similarly, we construct this variable for the domestic firms in the other four groups. The variable R&D intensity of higher-level-group MNEs is constructed by taking the average R&D intensity of the foreign firms in a group with higher labor productivity, compared with the group of the domestic firm, and are also in the same four-digit sector of the domestic firm. For example, suppose a domestic firm is in Group 1. For this domestic firm, the variable R&D intensity of the higher level group MNEs is calculated by taking the average R&D intensity of the foreign firms in Group 2 and in the same four-digit sector of the domestic firm. For a domestic firm in Group 2, the average R&D intensity of the foreign firms in Group 3 and in the same four-digit sector of the domestic firm is taken as the value of the variable. Different from Ornaghi (2006), we take 1 as the value of the variable MNE R&D intensity of the higher-level group for a domestic firm in Group 5, i.e., the group with the highest labor productivity, because 1 represents the upper bound of the R&D intensity

[21] In our study, a firm classified in a relatively high-labor productivity group would be equipped with more advanced machinery and equipment or have established a more efficient organizational and management structure.

[22] The labor productivity of Groups 1, 2, 3, 4, 5 is in an ascending order, i.e., Group 1 has the lowest labor productivity, and Group 5 has the highest labor productivity.

of a firm. This numerical manipulation is justified by the analysis of our data in Table 1 that demonstrated foreign firms in the groups of higher labor productivity generally have higher R&D intensity. Similarly, we construct the variable R&D intensity of lower-level-group MNEs by entering the average R&D intensity of the foreign firms in the group directly below the group of the domestic firm. For example, for a domestic firm in Group 2, the average R&D intensity of the foreign firms in Group 1 and in the same four-digit sector of the domestic firm is taken as the value of the variable R&D intensity of lower-level-group MNEs. For a domestic firm in Group 1, i.e., the group of lowest labor productivity, 0 is taken as the value of the variable because foreign firms in the group of lower productivity tend to have lower R&D intensity (Table 1). The methodology of constructing the variables of R&D intensity of same-group MNEs, R&D intensity of higher-level-group MNEs, and R&D intensity of lower–level-group MNEs is summarized in Table 2.

(Here insert Table 1)
(Here insert Table 2)

Incorporating the three variables into our general econometric framework, we further identify our econometric function as

(11) *(R&D intensity of domestic firm)$_{ijt}$ = f {(R&D intensity of same-group MNEs)$_{jt}$, (R&D intensity of higher-level- group MNEs)$_{jt}$, (R&D intensity of lower-level-group MNEs)$_{jt}$, (control variables)$_{ijt}$},*

where *i*, *j*, *t* represent a firm, a four-digit level industry, and time, respectively.

By constructing the variables and estimating the coefficients of R&D intensity of same-group MNEs, R&D intensity of higher-level-group MNEs, and R&D intensity of lower-level-group MNEs, we can identify how foreign firms with different levels of technology and management capabilities affect the R&D investment decisions of domestic firms. In other words, we can test how the technology distance between domestic and foreign firms determines the impact of foreign R&D investment on domestic R&D decisions. Our econometric strategy of analyzing

Equation 11 is to run the regression on four sub-samples of domestic firms separately. The first sub-sample includes the domestic firms of Groups 1 (the lowest labor productivity group), 2, 3, and 4, and excludes the domestic firms of Group 5 (the highest labor productivity). The second sub-sample includes the domestic firms of Groups 1, 2, and 3, and excludes domestic firms of Groups 4 and 5. Regressing on the two sub-samples separately allows us to focus on domestic firms with relatively low technology and management capabilities and to examine the effect of technology distance on the relationship between the R&D investments of these domestic firms and those of MNEs. By the same token, we run regressions using the other two sub-samples that focus on domestic firms with relatively high technology and management capabilities. The third sub-sample includes the domestic firms of Groups 2, 3, 4, and 5, and excludes the domestic firms of Group 1; the fourth sub-sample includes the domestic firms of Groups 3, 4, and 5 and excludes the domestic firms of Groups 1 and 2. The regression functions that differentiate the two types of domestic firms are presented in the following:

(12) *(R&D intensity of low-capability domestic firm)*$_{ijt}$ *= f {(R&D intensity of same-group MNEs)*$_{jt}$*, (R&D intensity of higher-level-group MNEs)*$_{jt}$*, (R&D intensity of lower-level-group MNEs)*$_{jt}$*, (control variables)*$_{ijt}$*},*

and

(13) *(R&D intensity of high-capability domestic firm)*$_{ijt}$ *= f {(R&D intensity of same-group MNEs)*$_{jt}$*, (R&D intensity of higher-level-group MNEs)*$_{jt}$*, (R&D intensity of lower-level-group MNEs)*$_{jt}$*, (control variables)*$_{ijt}$*},*

where *i*, *j*, *t* represent a firm, a four-digit level industry, and time, respectively.

To examine the robustness of the results obtained by classifying the firms into five groups, we also divide the firms into three groups, each of which contains one-third of all the firms, and then estimate the coefficients. We compare the estimation of the five- and three-group approaches in Section 3.4.

Another type of "distance" between domestic and foreign firms is geographical distance. We make use of the geographical code in the dataset to identify the geographical location of each firm. We construct three additional variables: R&D Intensity of MNEs within a City, R&D Intensity of MNEs within a Province, and R&D Intensity of MNEs within Neighboring Provinces. For a domestic firm, R&D Intensity of MNEs within a City is the average R&D intensity of foreign firms that are in the same four-digit sector and in the same city of the domestic firm. R&D Intensity of MNEs within a Province is the average R&D intensity of foreign firms that are in the same four-digit sector, in the same province, but in a different city of the domestic firm. By the same token, R&D Intensity of MNEs within Neighboring Provinces is the average R&D intensity of foreign firms that are in the same four-digit sector, within the area of the same province plus neighboring provinces[23], but in a different city of the domestic firm. Foreign firms encompassed by the variable R&D Intensity of MNEs within Neighboring Provinces are spread throughout a wider area than those included in the calculation of variable R&D Intensity of MNEs within a Province. The geographical areas covered by these two variables overlap, but they are mutually exclusive to the area covered by the variable R&D Intensity of MNEs within a City. As a result, the variables R&D Intensity of MNEs within a Province and R&D Intensity of MNEs within Neighboring Provinces enter the regression separately. The regression functions are presented in the following:

(14) (R&D intensity of domestic firm)$_{ijt}$ *= f {(R&D Intensity of MNEs within a City)*$_{jt}$*, (R&D Intensity of MNEs within a Province)*$_{jt}$*, (control variables)*$_{ijt}$*},*

and

(15) (R&D intensity of domestic firm)$_{ijt}$ *= f {(R&D Intensity of MNEs within a City)*$_{jt}$*, (R&D Intensity of MNEs within Neighboring Provinces)*$_{jt}$*, (control variables)*$_{ijt}$*},*

where *i*, *j*, *t* represent a firm, a four-digit level industry and time, respectively.

[23] The list of neighboring provinces for each province in our data is presented in Table 10 in the Appendix.

Our dataset shows that among all the provinces, Guangdong province hosts the largest number of foreign and domestic ICT firms. Shanghai and Jiangsu follow to host the second and third largest number of ICT firms. However, the number of firms located in Guangdong is higher than that in Shanghai and Jiangsu combined. Given the importance of Guangdong province to the Chinese ICT industry, we single out the data of the firms located in Guangdong and compare the results based on these data to the results obtained from firms throughout the country.

3.2.2 Control variables

Since more financial resources allow a firm greater opportunity to experiment and less stringent requirements for performance, they contribute to risky investments in R&D. That is, the more financial resources a firm has, the more likely it will invest in R&D or increase R&D investment. Following studies on slack resources by Greve (2003), Daniel et al. (2004) and Tan and Peng (2004), we include the ratio of administrative, financial, and selling expenses to sales value in the function to measure the financial resources of a firm.

Schumpeter (1950) was among the first to hypothesize that large firms in a mature capitalist economy generate a disproportionately large share of society's technological advances. Scholars who support this hypothesis have articulated that larger firms possess larger-scale, internally-generated funds, so they secure more resources with which to conduct risky R&D projects. Scale economies of R&D activity and return to R&D investment given a larger volume of sales also contribute to the advantage of larger firms. However, Cohen et al. (1987) argued that these points were flawed because of inadequate attention to the unit of analysis and to industry effects. They found overall firm size has a very small, statistically insignificant effect on business unit R&D intensity. In a recent study, Lee and Sung (2005) contested that firm size does not directly affect R&D intensity, but it does exert influence by affecting firm-specific technological competence. Although no consensus was reached on the relationship between firm size and R&D intensity in previous literature, we include the number of employees of a firm divided by the average number of the employees of all firms in the database as a control variable in our analysis.

Before conducting R&D activities, a firm must first invest in sophisticated technological equipment (Del Canto and Gonzalez, 1999). Investment in R&D equipment, similar to investment in ordinary machinery and production, is typically classified as fixed asset investment. A firm investing more in fixed assets, i.e. having higher capital intensity, is more likely to expand its R&D investment. Therefore, we include the ratio of fixed asset investment to added value as an explanatory variable to control for the effect of capital intensity on R&D investment.

Committed to fixed asset investment in R&D equipment, a firm also has to invest in human capital to build an efficient R&D team consisting of scientists and technicians with the proper qualifications, knowledge, and skills. Their experience and knowledge constitute the human resources of the firm, which contribute to the success of R&D projects. Following Del Canto and Gonzalez (1999), we use compensation per employee of the firm, which is the total compensation divided by the number of employees, as a proxy variable for the human resources of the firm.

The relationship between industry R&D intensity and market structure has been extensively investigated in the literature of industrial organization. According to Lee (2005), a number of studies found that the relationship between industry R&D intensity and market concentration can be described as an inverted-U shape. This indicates that moderately concentrated industries invest more in R&D activity than either highly competitive or highly concentrated industries. Bearing this in mind, we include in the regression a variable of the Herfindahl-Hirschman Industrial Concentration Index (HHI), calculated at the four-digit sector level, to account for the potential impact of market structure on a firm's R&D investment.

We also include several ownership and year dummy variables in the functions to control for ownership and time effect, respectively. The definitions of all the dependent and independent variables are summarized in Table 3, and the descriptive statistics of the variables are displayed in Table 4.

(Here insert Table 3)
(Here insert Table 4)

3.3 Estimation methodology

More than half of the domestic firms in our dataset did not conduct R&D during the observation period, so the R&D intensity of these firms was zero. This type of dependent variable is known as a “censored dependent variable,” i.e., the values of the variables in a certain range are all reported as a single value, e.g., zero. The conventional linear regression method is not able to distinguish between non-linear “zero” observations and continuous observations. Thus, we use the Tobit model as our baseline model. Moreover, although some time-invariant characteristics of domestic firms could also affect the dependent variable, their impact is not captured by the baseline Tobit model. Therefore, we run a panel Tobit model to control for these unobserved firm-specific factors.

The theoretical model presented in Section 2 clearly shows that the R&D intensity of foreign firms is endogenous in structural functions because of strategic interaction between a foreign firm and a domestic firm. To correct the bias caused by endogeneity of the explanatory variable, we instrument the R&D intensity of foreign firms with two variables: new-product intensity, defined as new-product value divided by the industrial output, and the ratio of administrative, financial, and selling expenses to sales value.

Legitimate instrumental variables need to be highly correlated with the endogenous variable but not correlated with the residual of the structural function. R&D activity leads to the development of new products, so R&D intensity is correlated with new product development. However, R&D investment of a host country firm in a particular four-digit sector could not substantially impact the average new product intensity of all the MNEs in that sector. In this sense, new-product intensity is a qualified instrumental variable. In Section 3.2.2, we argued that a firm’s financial resources contribute to its decision to invest in R&D. Therefore, the R&D investment variable is highly correlated with the variable measuring a firm’s financial capability. Furthermore, R&D decision of a host country firm can hardly affect the average ratio of the administrative, financial, and selling expenses to the sales value of all the MNEs in the same four-digit industry sector. Therefore, the ratio of administrative, financial, and selling expenses to sales value is a valid instrument variable of the R&D intensity of foreign firms. The definition of the two instrumental variables is also summarized in Table 3.

3.4 Empirical results

The estimation results of Function 11 are presented in Table 5. The coefficients of R&D intensity of lower-level-group MNEs are significant and positive in all four regression models. The coefficients of R&D intensity of higher-level-group MNEs and R&D intensity of same-group MNEs are significant and positive in three of the four regression models. To correct the endogeneity of explanatory variables, we instrument the four statistically significant variables in the Tobit model results, i.e., R&D intensity of same-group MNEs and R&D intensity of lower-level-group MNEs in the five-group results and R&D intensity of higher-level-group MNEs and R&D intensity of lower-level-group MNEs in the three-group results, and report the instrumental variable regression results in Table 6. The table shows that R&D intensity of higher-level-group MNEs and R&D intensity of lower-level-group MNEs are all maintained to be statistically significant in instrumental variable Tobit models. The statistical significance of R&D Intensity of same-group MNEs has changed. Overall, the prevalent and robust positive signs of the coefficients indicate that the R&D offshoring of MNEs stimulated the R&D investment of domestic firms in the ICT sector of China.

(Here insert Table 5)
(Here insert Table 6)

In addition, the results presented in Table 5 reveal that a host country firm with greater financial resources, a larger size, and more R&D human resources is more likely to invest more in R&D. Moreover, the more concentrated an industry sector is, the more a host country firm will invest in R&D. However, contradictory to our prediction, a firm investing more in fixed assets tends to invest less in R&D. The average R&D intensity of host country firms in the four-digit sector has no statistically significant influence on R&D decisions of an individual firm. We also find that limited liability and stock companies tend to invest more in R&D than firms of other ownership status. The R&D investment level of domestic firms in 2001 exhibited a statistically significant difference from that of domestic firms in 2002, but it did not between 2001 and 2003 or between 2001 and 2005.

We present the regression results of Functions 12 and 13 in Tables 7 and 8 for the five-group and three-group approaches, respectively. Table 7 shows that when we use the sub-sample of domestic firms in Groups 1, 2, and 3 (domestic firms with relatively low technology and management capability) and exclude the domestic firms of Groups 4 and 5 in the regression, the coefficients of R&D intensity of higher-level-group MNEs and R&D intensity of same-group MNEs are insignificant; however, the coefficients of R&D intensity of lower-level-group MNEs are generally significant and positive in the regressions. When we use the sub-sample of domestic firms in Groups 2, 3, 4 and 5 or Groups 3, 4, and 5 (domestic firms with relatively high technology and management capability) in the regression, the coefficients of R&D intensity of lower-level-group MNEs are insignificant; however, the coefficients of R&D intensity of higher-level-group MNEs and R&D intensity of same-group MNEs are generally significant and positive in the regressions. Table 8 shows a similar pattern in the results for the three-group approach, implying the robustness of our results.

(Here insert Table 7)
(Here insert Table 8)

The regression results of Functions 14 and 15 are presented in Table 9. The regression using a full sample reveals significant and positive effects of R&D intensity of MNEs within a city in both the Tobit model and the Panel Tobit model, but insignificant effects of R&D intensity of MNEs within a province and R&D intensity of MNEs within neighboring provinces. The regression analysis of host country firms in Guangdong province shows that R&D intensity of MNEs within a city is in general significant and has a positive impact on domestic firms' R&D intensity, but both R&D intensity of MNEs within a province and R&D intensity of MNEs within neighboring provinces have significantly negative effects on the R&D intensity of domestic firms.

(Here insert Table 9)

4. Discussion and Policy Implications

The empirical results using technological distance to measure the ease of learning in a domestic firm imply that R&D investment of host country firms in the ICT sector in China is generally positively affected by the R&D investment of MNEs. The R&D intensity of a domestic firm with relatively low technological and management capability is affected by the R&D investment of only those MNEs whose capabilities are lower than those of the domestic firms and not by the R&D investment of more advanced MNEs. For domestic firms with relatively high technological and management skills, we find that their R&D decisions are affected by only those MNEs whose capabilities are higher than those of the domestic firms and not by MNEs with lower technological and management capabilities.

The results based on geographical distance demonstrate that the R&D investment decisions of domestic firms in the ICT sector in China is positively affected by only the MNEs within the same city. The influence of the MNEs located outside of a city is relatively insignificant. Furthermore, the analysis of domestic firms in the Guangdong province shows that R&D investment by MNEs out of the city, but within the same province and neighboring provinces, has a negative impact. These findings, based on data from firms all over China and within Guangdong province, consistently reveal a geographical boundary for the positive impact of the R&D offshoring of MNEs in the Chinese ICT industry.

Given the insights derived from the theoretical model and empirical evidence, we argue that through industry policy, governments in emerging economies could promote the productivity growth of domestic firms.[24] In fact, industry policy that encourages cooperation between domestic and foreign firms and facilitates learning within domestic firms through R&D or innovation subsidy is already in place in emerging economies. Such sound policy could ensure success, as argued by Laderman et al. (2003). Their study suggested that a host country could unleash a sequence of investments by successfully inducing FDI from one or two important firms.

[24] Defined by Pack and Saggi (2006), an industry policy is a selective governmental intervention that promotes the economic growth of industry sectors in the way that would not occur in the absence of such intervention in the market equilibrium.

Our analyses shed new light on the relevance and implementation of industry policies conducive to technological learning in emerging economies.

First, governments of emerging economies should be cautious about allowing R&D offshoring by an MNE since its positive impact on the R&D investment decisions of a domestic firm would be only conditional. Second, our findings show that the limited technological and management capabilities of domestic firms would impede their benefiting from spillover generated by the R&D investment of MNEs. If an industry in a developing economy is relatively developed, industry policies favorable to foreign R&D investment would provide domestic firms with opportunities to learn from the more advanced foreign competitors. The knowledge gained from this process is essential if emerging economies are to achieve successful technological upgrading at a later stage. However, if a sector falls into the category of an "infant" industry, the government of the developing economy has reasons to be suspicious of the substantial positive impact of the R&D investment of MNEs on the R&D decisions of domestic firms. Even so, the R&D investment of MNEs could still exert a positive influence on the local economy such as increasing local employment opportunities.

Third, we find that the geographical barrier for the positive impact of the R&D investment of MNEs on the R&D decisions of domestic firms is insurmountable in the Chinese ICT industry. Since the positive impact is limited to certain geographical areas, local firms and residents only in these areas would be the primary beneficiaries of the R&D investment. Therefore, local governments should play an important role in forming effective industry R&D policy. The decisions related to fiscal incentives for R&D expenditures and funds for industrial R&D activities could be left to the discretion of local governments. Moreover, fierce competition among local governments in courting advanced foreign direct investment projects is not uncommon in the era of R&D offshoring. Our study interprets the behavior of local governments in the sense that technological spillover from MNE R&D investment could be relatively "local" in nature. Thus, what a region benefits from the establishment of advanced foreign R&D centers would not likely be shared with neighboring regions.

5. Conclusions

MNE R&D offshoring to emerging economies has become a prominent phenomenon in recent years. In this paper, we investigate how the R&D offshoring of MNEs affects the R&D investments of host country firms. To investigate this issue, we have developed a two-stage non-cooperative game as a theoretical foundation and gathered empirical evidence from a large dataset of 12,309 manufacturing firms in the ICT industry in China.

In general, we have found that domestic firms in the Chinese ICT industry have increased R&D investment in response to the R&D offshoring decisions of MNEs. This finding implies that the positive effects of spillover exceeded the negative effects of competition from the R&D offshoring of MNEs on the R&D investment of domestic firms. Nevertheless, the magnitude of the impact of MNEs is determined by the relative distance between the MNEs and the domestic firms. The R&D investment decisions of a domestic firm with relatively high technology and management skills would not be affected by the R&D investment of inferior MNEs. Similarly, the R&D decisions of a domestic firm with relatively low technology and management capabilities would not be positively affected by the R&D investment of more advanced MNEs. The positive impact of MNE R&D investment on domestic firms diminishes as the geographical distance between them increases.

Our findings provide important policy implications to both the host and the home countries of R&D offshoring. Understanding the response of host country competitors is not only critical if the MNEs are to choose the right R&D offshoring strategies but also important if policy makers in the MNEs' home countries are to successfully regulate the MNE R&D offshoring to emerging economies. For host country policy makers, our findings provide important implications regarding how emerging economies could leverage their FDI policy to facilitate technology spillover from the MNEs and technology learning in the domestic firms. The success of technology spillover and technology learning in host countries will greatly contribute to the long-term development of the indigenous innovation capabilities of domestic firms.

Our study is limited in scope because we investigate only intra-industry R&D spillovers, not R&D spillovers from MNEs in one industry to other industries in the host country, such as upstream and downstream industries. As a result, our findings could underestimate the overall positive effect of MNE R&D offshoring on host country firms. In addition to including upstream and downstream industry sectors in the analysis, this study could be extended to industries other than ICT, allowing the examination of the generalizability of our findings and the investigation of R&D spillover patterns in sectors other than ICT. Furthermore, this research could examine whether the potential influence of MNE R&D offshoring on the R&D investment of domestic firms would result in changes in the productivity of domestic firms.

Appendix

(Here insert Table 10)

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Table 1: Ranking of Average R&D Intensity of MNEs among Different Groups

	R&D Intensity					Ranking of R&D Intensity Among 5 Groups				
Four-digit Sector	Group 1 (Lowest labor productivity)	Group 2	Group 3	Group 4	Group 5 (Highest labor productivity)	Group 1 (Lowest labor productivity)	Group 2	Group 3	Group 4	Group 5 (Highest labor productivity)
4111	.0120	.0065	.0156	.0088	.0256	3	5	2	4	1
4112	.0104	.0019	.0019	.0135	.0203	3	5	4	2	1
4113	.0022	.0082	.0023	.0049	.0046	5	1	4	2	3
4119	.0041	.0018	.0016	.0060	.0062	3	4	5	2	1
4130	.0026	.0029	.0062	.0041	.0074	5	4	2	3	1
4141	.0024	.0000	.0002	.0020	.0009	1	5	4	2	3
4143	.0024	.0026	.0026	.0021	.0026	4	2	3	5	1
4151	.0010	.0032	.0022	.0009	.0010	3	1	2	5	4
4153	.0054	.0018	.0077	.0093	.0027	3	5	2	1	4
4155	.0055	.0048	.0003	.0048	.0081	2	3	5	4	1
4160	.0009	.0027	.0017	.0022	.0019	5	1	4	2	3
4171	.0015	.0008	.0015	.0023	.0091	3	5	4	2	1
4172	.0002	.0008	.0016	.0017	.0047	5	4	3	2	1
4182	.0002	.0000	.0010	.0113	.0368	4	5	3	2	1
4189	.0043	.0084	.0010	.0040	.0062	3	1	5	4	2
Sum of Ranks						52	51	52	42	28

Note:
1. The labor productivity of groups 1, 2, 3, 4, 5 is in an ascending order, i.e., Group 1 has the lowest labor productivity and Group 5 has the highest labor productivity.

Table 2: Methodology of Constructing the Variables of R&D Intensity of Lower-Level-Group MNEs, R&D Intensity of Same-Group MNEs, and R&D Intensity of Higher-Level-Group MNEs

A domestic firm in different groups	Variables		
	R&D intensity of lower-level-group MNEs	R&D Intensity of same-group MNEs	R&D intensity of higher-level-group MNEs
A domestic firm in Group 1 (lowest labor productivity)	0	A	B
A domestic firm in Group 2	A	B	C
A domestic firm in Group 3	B	C	D
A domestic firm in Group 4	C	D	E
A domestic firm in Group 5 (highest labor productivity)	D	E	1

Note:

1. The labor productivity of groups 1, 2, 3, 4, 5 is in ascending order, i.e., Group 1 has the lowest labor productivity, and Group 5 has the highest labor productivity.

2. A: Average R&D investment intensity of the MNEs in Group 1, which are also in the same four-digit sector of the domestic firm

B: Average R&D investment intensity of the MNEs in Group 2, which are also in the same four-digit sector of the domestic firm

C: Average R&D investment intensity of the MNEs in Group 3, which are also in the same four-digit sector of the domestic firm

D: Average R&D investment intensity of the MNEs in Group 4, which are also in the same four-digit sector of the domestic firm

E: Average R&D investment intensity of the MNEs in Group 5, which are also in the same four-digit sector of the domestic firm

Table 3: The Variables

Variable Name	Definition and Note
Domestic Firm R&D Intensity (Dependent Variable)	R&D expenditure of a domestic firm / Added value of a domestic firm
Domestic Firm R&D Intensity at Four-digit Sector Level (Independent Variable)	Sum of R&D expenditure of domestic firms in the same four-digit sector / Sum of added value of domestic firms in the same four-digit sector
R&D intensity of same-group MNEs[1]	Sum of R&D expenditure of MNEs in the same four-digit sector / Sum of added value of MNEs in the same four-digit Sector (The MNEs are classified into the same labor productivity group as the group of domestic firms)
R&D intensity of higher-level-group MNEs [1]	Sum of R&D expenditure of MNEs in the same four-digit sector / Sum of added value of MNEs in the same four-digit Sector (The MNEs are classified into a higher labor productivity group compared with the group of domestic firms)
R&D intensity of lower-level-group MNEs [1]	Sum of R&D expenditure of MNEs in the same four-digit sector / Sum of added value of MNEs in the same four-digit Sector (The MNEs are classified into a lower labor productivity group compared with the group of domestic firms)
Financial Resource	Administrative, financial and selling expenses / Sales
Firm Size	Number of employees / Average number of employees of firms in the sample
Fixed Asset Investment Intensity	Fixed asset investment /Added value
Human Resource	Employee compensation value / Number of employees
Herfindahl-Hirschman Industrial Concentration Index (HHI)	$\sum_{j=1}^{n}$ (Market share (Percentage) of j firm in a four-digit sector)^2
Ownership Dummy Variables	For domestic firms, the base group is “other domestic firms”. The dummy variables represent state-owned, collective, employee shareholding cooperatives, joint operation enterprises, limited liability companies, stock companies, private enterprises.
Year Dummy Variables	The base group is 2001. The dummy variables represent 2002, 2003 and 2005.
MNE R&D Intensity within a City	Average R&D intensity of MNEs that are in the same four-digit sector and within the same city or county of domestic firms.
MNE R&D Intensity within a Province	Average R&D investment intensity of MNEs that are in the same four-digit sector, in the same province but in a different city or county of domestic firms.
MNE R&D Intensity within Neighboring Provinces	Average R&D intensity of MNEs that are in the same four-digit sector, within the area of the same province plus neighboring provinces but in a different city or county of domestic firms.
MNE new-product intensity	Sum of new product value of MNEs in the same four-digit sector / Sum of output value of MNEs in the same four-digit Sector
Ratio of the administrative, financial and selling expenses to sales value of MNE	Sum of administrative, financial, and selling expenses of MNEs in the same four-digit sector / Sum of sales value of MNEs in the same four-digit Sector

Note: 1. a detailed definition of the variable is presented in Section 3.2.1.

Table 4: Summary Statistics of Variables

Year	Number of Domestic Firms		Domestic Firm R&D Intensity (Dependent Variable)	Domestic Firm R&D Intensity at Four-digit Sector Level (Independent Variable)	R&D Intensity of Same-group MNEs	R&D Intensity of Higher-level Group MNEs	R&D Intensity of Lower-level-Group MNEs	Financial Resource	Firm Size	Fixed Asset Investment Intensity	Human Resource	Herfindahl-Hirschman Industrial Concentration Index (HHI)
2001	2294	Mean	.0065	.011	.0026	.16	.0020	.66	.82	20	13	.039
		Standard Deviation	.025	.017	.0045	.36	.0045	13	2.2	510	20	.041
		75th Percentile	.0011	.0092	.0026	.0074	.0015	.27	.67	1.9	14	.058
2002	2486	Mean	.012	.013	.0028	.17	.0018	.34	.79	5.5	14	.042
		Standard Deviation	.20	.019	.0039	.37	.0032	2.0	2.4	72	12	.043
		75th Percentile	.0021	.011	.0028	.0081	.0016	.26	.63	1.7	14	.062
2003	2727	Mean	.014	.012	.0035	.18	.0023	.34	.73	2.6	15	.034
		Standard Deviation	.31	.018	.0061	.38	.0051	6.2	2.3	21	14	.037
		75th Percentile	.0022	.011	.0029	.0072	.0020	.22	.59	1.4	17	.046
2005	4046	Mean	.010	.014	.0053	.19	.0034	.17	.63	2.7	17	.032
		Standard Deviation	.031	.0091	.0085	.38	.0039	.57	2.3	32	14	.052
		75th Percentile	.0014	.020	.0047	.013	.0044	.18	.50	1.2	19	.041

Table 5: Effect of MNE R&D Activity: Ease of Learning Measured by Labor Productivity

Independent Variable	The R&D Intensity of Domestic Firms as Dependent Variables Five Groups Tobit Model	 Panel Tobit Model	 Three Groups Tobit Model	 Panel Tobit Model
R&D Intensity of Same-group MNEs	.84(.47)*	.30(.11)***	.18(.43)	.24(.10)**
R&D Intensity of Higher-level-group MNEs	.011(.0084)	.0080(.0026)***	.037(.0070)***	.015(.0022)***
R&D Intensity of Lower-level-group MNEs	1.7(.73)**	.44(.18)**	2.7(.67)***	.47(.16)***
Average R&D Intensity of Domestic Firms in the Same Four-digit Sector (Independent Variable)	.050(0.82)	.067(.062)	.21(.21)	.095(.061)
Financial Resource	.037(.00038)***	.00049(.00031)	.037(.00039)***	.00049(.00030)
Firm Size	.0066(.0011)***	.0018(.00037)***	.0067(.0011)***	.0018(.00037)***
Fixed Asset Investment Intensity	-.0022(.000035)***	-.000041(.000020)**	-.0022(.000035)***	-.000040(.000020)**
Human Resource	.0019(.00018)***	.00069(.000050)***	.0017(.00018)***	.00064(.000050)***
Herfindahl-Hirschman Industrial Concentration Index (HHI)	.28(.074)***	.077(.019)***	.23(.074)***	.063(.019)***
Ownership Dummy Variables that are Statistically Significant at 10 Percent	limited liability companies and stock companies	stock companies	limited liability companies and stock companies	stock companies
Year Dummy Variables that are Statistically Significant at 10 Percent	2002 and 2003	2002	2002	2002
Number of Observations	11553	11553	11553	11553
Number of Groups for Panel Model		6456		6456
Likelihood-ratio Chi-squared Statistics for Tobit Model / Wald Chi-squared Statistics for Panel Tobit Model	2613.6***	625.8***	2650.3***	672.5***

Note: 1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.

Table 6: Instrumental Variable Tobit Model

Independent Variable	Instrumental Variable Tobit Model (The R&D Intensity of Domestic Firms as Dependent Variables)			
	Five Groups		Three Groups	
	R&D Intensity of same-group MNEs is instrumented	R&D intensity of lower-level-group MNEs is instrumented	R&D intensity of higher-level-group MNEs is instrumented	R&D intensity of lower-level-group MNEs is instrumented
R&D Intensity of Same-group MNEs	-2.4(1.7)	-.68(.61)	.073(.43)	-.84(.50)*
R&D Intensity of Higher-level-group MNEs	.020(.0096)**	-.0075(.0097)	.045(.0074)***	.030(.0072)***
R&D Intensity of Lower-level-group MNEs	2.8(.93)***	12(2.7)***	2.6(.67)***	9.3(1.8)***
Wald Test of Exogeneity (Chi-squared Statistics)	3.6*	15.9***	12.0***	15.4***

Note:

1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%l, * denotes a significance level of 10%.

2. To simplify, the coefficients of the controlling and dummy variables are not reported.

Table 7: Impact of Technological Distance: Firms Divided into Five Groups

Independent Variable	The R&D Intensity of Domestic Firms as Dependent Variables							
	Groups 1, 2, 3, 4		Groups 1, 2, 3		Groups 2, 3, 4 and 5		Groups 3, 4 and 5	
	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model
R&D Intensity of Same-group MNEs	1.0(.89)	.38(.15)**	.97(1.2)	.24(.24)	.48(.19)***	.22(.12)*	.41(.17)**	.23(.11)**
R&D Intensity of Higher-level-group MNEs	.55(.61)	.25(.11)**	.40(1.3)	.29(.26)	.0078(.0033)**	.0088(.0026)***	.0040(.0028)	.0067(.0026)***
R&D Intensity of Lower-level-group MNEs	2.2(.93)**	.21(.16)	4.8(1.5)***	1.0(.31)***	.49(.29)*	.22(.18)	.0052(.26)	-.15(.18)

Note:

1. The data in parentheses are standard deviations. *** denotes a significance of 1%, ** denotes a significance of 5%, * denotes a significance of 10%.
2. The labor productivity of groups 1, 2, 3, 4, 5 is in ascending order, i.e., Group 1 has the lowest labor productivity, and Group 5 has the highest labor productivity.
3. To simplify, the coefficients of the controlling and dummy variables are not reported.

Table 8: Impact of Technological Distance: Firms Divided in Three Groups

Independent Variable	The R&D Intensity of Domestic Firms as Dependent Variables			
	Group 1 and 2		Group 2 and 3	
	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model
R&D Intensity of same-group MNEs	-.86(1.1)	.0081(.22)	.25(.15)*	.20(.11)*
R&D intensity of higher-level-group MNEs	1.2(.75)	.21(.15)	.012(.0026)***	.011(.0025)***
R&D intensity of lower-level-group MNEs	6.1(1.5)***	1.2(.32)***	.67(.24)***	.28(.18)

Note:

1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.
2. To simplify, the coefficients of the controlling and dummy variables are not reported.

Table 9: Effect of MNE R&D Activity: Ease of Learning Measured by Geographical Distance

Independent Variable	The R&D Intensity of Domestic Firms as Dependent Variables							
	Overall Domestic Firms				Domestic Firms in Guangdong Province			
	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model	Tobit Model	Panel Tobit Model
R&D Intensity of MNEs within a City	.61(.24)**	.42(.16)***	.65(.24)***	.47(.16)***	1.4(.57)**	.73(.52)	1.5(.58)***	.88(.53)*
R&D Intensity of MNEs within a Province	-.26(.38)	-.34(.25)	-	-	-7.2(2.4)***	-8.9(2.3)***	-	-
R&D Intensity of MNEs within Neighboring Provinces	-	-	-1.0(1.1)	-1.1(.74)	-	-	-9.9(4.1)**	-11.8(4.0)***

Note:

1. The data in parentheses are standard deviations. *** denotes a significance level of 1%, ** denotes a significance level of 5%, * denotes a significance level of 10%.
2. To simplify, the coefficients of the controlling and dummy variables are not reported.

Table 10: List of Neighboring Provinces

Province	Neighboring Provinces
Beijing	Tianjin, Hebei
Tianjin	Beijing, Hebei
Hebei	Beijing, Tianjin, Shanxi, Inner Mongolia, Liaoning, Shandong, Henan
Shanxi	Hebei, Inner Mongolia, Henan, Shaanxi
Inner Mongolia	Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Shaaxi, Gansu, Ningxia
Liaoning	Hebei, Inner Mongolia, Jilin
Jilin	Inner Mongolia, Liaoning, Heilongjiang
Heilongjiang	Inner Mongolia, Jilin
Shanghai	Jiangsu, Zhejiang
Jiangsu	Shanghai, Zhejiang, Anhui, Shandong
Zhejiang	Shanghai, Jiangsu, Anhui, Fujian, Jiangxi
Anhui	Jiangsu, Zhejiang, Jiangxi, Henan, Hubei
Fujian	Zhejiang, Jiangxi, Guangdong
Jiangxi	Zhejiang, Anhui, Fujian, Hubei, Hunan, Guangdong
Shandong	Hebei, Jiangsu, Henan
Henan	Hebei, Shanxi, Anhui, Shandong, Hubei, Shaanxi
Hubei	Anhui, Jiangxi, Henan, Hunan, Chongqing, Shaanxi
Hunan	Jiangxi, Hubei, Guangdong, Guangxi, Chongqing, Guizhou
Guangdong	Fujian, Jiangxi, Hunan, Guangxi, Hainan
Guangxi	Hunan, Guangdong, Hainan, Guizhou, Yunnan
Hainan	Guangdong, Guangxi
Chongqing	Hubei, Hunan, Sichuan, Guizhou, Shaanxi
Sichuan	Chongqing, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai
Guizhou	Hunan, Guangxi, Chongqing, Sichuan, Yunnan
Yunnan	Guangxi, Sichuan, Guizhou, Tibet
Gansu	Inner Mongolia, Sichuan, Shaanxi, Qinghai, Ningxia, Xinjiang
Qinghai	Sichuan, Tibet, Gansu, Xinjiang
Ningxia	Inner Mongolia, Shaanxi, Gansu
Xinjiang	Tibet, Gansu, Qinghai

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