KNOWLEDGE SPILLOVERS THROUGH MULTINATIONAL FIRMS IN HIGH-TECH AND LOW-TECH INDUSTRIES

[JOB MARKET PAPER]

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Abstract. Although economists and policy makers have devoted considerable attention to the technology spillovers from foreign to domestic firms, they have not come to a common conclusion. In order to have a deep understanding of the complex FDI knowledge spillovers, this study disaggregates the total spillovers into high- and low-tech industries, in contrast with earlier work that have only examined its aggregate spillovers. I develop a simple theory to explain the mechanism through which new technology of the foreign firms is transmitted to the domestic firms by analyzing the endogenous decision of multinational firms on the location of production of intermediate goods. The model shows different patterns of knowledge spillovers in the high- and low-tech industries: immediate catch-up to the foreign firm's advanced technology but unsustainable technology spillovers in the low-tech sectors while slow catch-up to the foreign firm's technology but continual knowledge spillovers in the high-tech sectors. The U.S. data for the years 1987-1995, broken down into high- and low-tech industries, support the model. The pattern of knowledge spillovers in the high- and low-tech industries are hump-shaped, but in low-tech industries it reaches its peak after a sharp increase while in the high-tech industries it hits its peak following a smooth increase.

Keywords: Multinational corporations, foreign direct investment(FDI), knowledge spillovers, technology transfer, high-tech industries, low-tech industries

JEL Classification: F23, D92, D83, L24, O14

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1. Introduction

Differences in income across countries are largely explained by productivity variations, and technology plays an important role in determining productivity. However, most of the world's technology development is conducted in only a few developed countries even though R&D expenditures in some developing countries, such as China and India, are recently increasing. Therefore, international diffusion of technology is very important in reducing a productivity gap and furthermore income variations across countries.

Multinational firms, enterprises that control and manage production establishments which span two or more countries, have played a fundamental role in transferring capital, high skilled labor, technology, and final and intermediate products. Many countries provide the multinational firms with various incentives, such as lower income taxes, tax holidays, import duty exemptions and subsidies, to attract multinational firms to their country based on the belief that they generate positive externalities in the host country. Among the positive externalities, technology transfer and then productivity growth of the domestically-owned firms are expected most by policy makers.

In fact, there are several plausible arguments that domestic firms obtain benefits from the entry of the multinational firms, in particular, in the form of technology transfer. First, the multinational firms are well known to be larger and more productive and to do more R&D than purely domestically-owned firms. In the year 2008, total R&D spending by the eight largest multinational firms was larger than that by all individual countries, except for the United States and Japan(OECD 2010). Also, there are several mechanisms through which modern technology of the multinational firms may be transferred to the domestic firms: hiring employees away from multinational firms, imitating their products, or establishing vertical backward/forward linkages with foreign firms. Additionally, the entry of multinational firms may lead to severe competition in the host country market and force domestic firms to improve their efficiency. However, since the multinational firms cannot fully internalize all the benefits of the domestic firms, the knowledge spillovers may arise improving the host firms' productive efficiency. Despite these favorable reasons for technology transfer by multinational firms, empirical evidence has not yet produced a common conclusion.

Case studies on technology transfer from multinational to domestic firms present mixed results. Mauritius and Bangladesh experienced a large increase in textile exports following the entries of multinational firms(Rhee and Belot, 1989). Considering that exporters are more productive than non-exporters, it shows evidence of technology transfer by multinational firms. On the other hand, Germidis(1977) found no evidence of technology transfer in his study of 65 foreign affiliates in 12 developing countries.

Also, although many empirical researchers have tried to examine the knowledge spillovers from foreign direct investment(FDI) over the past few decades, the results are inconclusive. According to the Gorg and Greenway(2004) which reviewed more than 40 empirical studies on the FDI spillovers, 20 found positive spillovers, 17 cases yielded insignificant results, and 8 negative knowledge spillovers. Of course, they cover different countries and time periods, and also apply different econometric and measurement methods. Researchers motivated by these mixed empirical results have attempted to disentangle complicated patterns of FDI spillovers, by figuring out channels of the knowledge transfer and various factors which influence knowledge transfer process such as absorptive capacity of the local firms or multinational firms' nationalities.

However, previous studies have only examined total effects of multinational firms on the productivity of domestically-owned firms, overlooking that multinational firms may differently behave in high- and low-tech industries. This paper investigates whether the knowledge spillovers depend on the technological complexity of industries, and finds that the spillovers have different patterns in high- and low-tech industries. I first develop a simple theory which explains a mechanism by which new technology of foreign firms is transmitted to host country firms by analyzing the endogenous decision of multinational firms on the location of production of intermediate goods. The main idea behind the model comes from the two facts: intermediate goods vary in technological complexity from simple to complex intermediate goods, and the production of complex intermediate goods in the host country incurs significant loss of efficiency, which is called technology transfer cost. Those facts imply that multinational firms in high-tech industries which need more complex intermediate goods bring most of intermediate goods from their parent country to avoid high technology transfer cost, building a limited relationship with local firms and restricted channels of technology transfer. On the other hand, multinational firms in low-tech industries, which mostly use simple intermediate goods, procure the majority of intermediate goods within the host country, establishing significant linkages with local suppliers and large channels of technology transfer. However, as technology transfer cost decreases, the production of complex intermediate goods would move to the host country, which is followed by extension of spillover channels and additional technology transfer. In sum, the model results in different patterns of knowledge spillovers in high- and low-tech industries: immediate large but unsustainable increases in spillovers in low-tech sectors, while slow but continual knowledge spillovers occur in high-tech sectors.

The U.S. firm-level data from Compustat for the years 1987-1995 support the model. The empirical results show that the patterns of knowledge spillovers in high- and low-tech industries are hump-shaped, but in the low-tech industries domestic firms rapidly keep up with the foreign firm's productive efficiency with no sustainable increases in spillovers, while in the high-tech industries they reach the foreign firm's level at very low speed but there are continual knowledge spillovers. In this empirical study, I adopt a quadratic regression equation to capture a non-linear relationship between domestic firm's performance and technology transfer cost, Second, I use industry-level data on imports shipped to foreign affiliates from their parent companies obtained from the OECD in order to measure the technology transfer cost. It is based on the assumption that a low technology transfer cost is associated with a greater procurement of intermediate goods within the host country, and thus less intra-firm imports of intermediate goods from parent companies. Third, I apply the semiparametric Olley-Pakes method to properly measure total factor productivity of domestic firms.

My study is unique in several dimensions. First, I look at knowledge spillovers in high- and low-tech industries, respectively, since their different technological features may cause differences in the knowledge spillovers. It challenges the view that all inward FDI is equally valuable in terms of productivity benefits regardless of industries. However, my results suggest that FDI spillovers depend on technological complexity of the industries, and also on the technology transfer cost. Second, as briefly mentioned above, the empirical analysis is based on the data of intra-firm imports as a proxy for the extent to which multinational firms have interactions with local firms. The previous studies usually use employment or production share of foreign firms to measure the foreign presence in the host country, leaving channels of knowledge spillovers as a black box. However, this paper suggests explicit mechanism of knowledge spillovers and measure it with observable data. Third, I show that the multinational firm's impact on the local firm's productivity is better explained with a quadratic function. The existing literature, excepting for a few studies, is confined to examining a linear relationship between foreign presence and domestic firms' productivity. The notable exception is Buckley, Clegg, and Wang(2007), in which they found that the impacts of the multinational firms on the domestic firm's performance have a curvilinear relationship, and also they argue that the foreign firm's impacts depend on the nationality of ownership of foreign investors.

The remainder of this paper is constructed as follows: The following section lays out a model which explains a knowledge spillovers mechanism. Section three describes the data and estimation strategy. The estimation results are presented in section four, and section five provides some concluding remarks.

2. Literature review

FDI has been considered as one of the important knowledge spillover channels. Some papers theoretically support the appearance of multinational firms in the world economy.(Markusen 1984, Markusen and Venables 1998). Since firm-specific activities such as R&D, advertising, marketing, and management services have a characteristic of public goods, multinational firms do not need to duplicate them whenever they open new affiliates. Hence, they take advantage of the economies of multi-plant operation and market expansion by establishing new affiliates in other countries. Also, Rodriguez-Clare(2007) argues that the gains from openness, which includes not only trade but also other venues, are much higher than the gains from only trade. In other words, there is another channel through which countries interact and large positive impacts accrue to the economy. FDI could be one of the potential channels.

There are a number of case studies on the FDI spillovers. These studies bear mixed evidence on the role of multinational firms in generating technology diffusion to domestic firms, some find evidence of the knowledge spillovers but others do not.

Many international economists have attempted to go beyond qualitative case studies. Following Caves(1974), Globerman(1979a), and Blomstrom and Persson(1983), many empirical studies have poured out. Even though a large body of literature has tried to show empirically the existence and degree of the horizontal knowledge spillovers through multinational firms, they have come to mixed results of strongly positive, negative, or even insignificant horizontal knowledge spillovers. Keller and Yeaple(2009) and Blomstrom and Wolff(1994) showed that the presence of foreign firms is associated with the growth of host firm's productivity. On the other hand, some papers argued that foreign presence does not seem to have positive impact on the local productivity. Aitken and Harrison(1999) and Blomstrom(1986a) found that foreign presence rather reduces productivity of domestically-owned firms by the so-called market-stealing effect. Also, Haddad and Harrison(1993) concluded that foreign firms do not generate knowledge spillovers in the host country.

The empirical ambiguity has become a major motivation for further studies. Based on the fact that the previous studies have treated the mechanisms by which the knowledge spillovers occur as a black box, the following papers have tried to explicitly explain spillover channels. First, Javorcik(2004), and Lin and Saggi(2007) took into account vertical linkages as one of the spillover channels. When multinational firms make contracts with local firms to purchase intermediate goods, foreign firms may teach local suppliers how to efficiently produce goods or how to improve the production management to meet their higher standards of product quality or on-time delivery. Second, worker turnover is considered as a spillover channel in some papers. The foreign firms provide local workers with on-the-job training or better work experience. If the workers are hired by domestic firms when they leave the foreign firms, they would use their advanced techniques and knowledge for domestic firms. Markusen and Trofimenko(2007), Gorg and Strobl(2005), and Poole(2007) supported the argument using firm- or establishment-level data. The third channel is called demonstration effects. The local firms learn a modern technology of the foreign firms through the imitation or reverse-engineering. Cheung and Lin(2004) and Hale and Long(2006) showed positive spillovers effects through demonstration effects, but this channel does not seem to be as strong as previous channels.

Another attempt to resolve the inconclusiveness of the FDI spillovers is to examine factors that influence the spillovers, such as nationality of the foreign firms, absorptive capacity of the domestic firms, or the characteristics of the foreign firm's activities. Griffith, Redding, and Simpson(2003) argued that the further is the distance from the technology frontier, the greater is the speed of technology transfer, and foreign multinationals play an important role in the technology transfer by pushing the technology frontier out and so increasing the speed of convergence to the advanced technology. Gorg, Hijzen, and Murakozy(2009) presented that labor-intensive activities of foreign affiliates are unlikely to generate positive productivity spillovers while capital-intensive foreign affiliates increases the productivity of the local firms. Bukley, Clegg, and Wang(2007) showed that, among multinational firms which open their affiliates in China, the firms from Hong Kong, Macau, and Taiwan do not generate knowledge spillovers to Chinese firms while the firms form U.S., Europe, and Japan bring positive externalities to China.

This paper looks at knowledge spillovers in the high- and low-tech industries based on the idea that different technological complexity of the industries would force multinational firms to make a different decision. Also, this paper suggests explicit mechanism by which new technology of foreign firms are transferred to the local firms within the same industry by combining vertical and horizontal knowledge spillovers.

3. Theory

3.1. **Overview.** I employ a model of Keller(2009) to illustrate technology transfer cost and the endogenous decision of multinational firms on the location of the production of intermediate goods. Before explaining the details of the framework, I first give a background of the model; in particular, the mechanism of knowledge spillovers from multinational to locally-owned firms and the intuition of how they are differently operating in high- and low-tech industries.

In this world, there are two countries, a parent country and a host country, and two sectors, high-tech and low-tech sectors. Also, there are four different kinds of agents: headquarters and affiliates of multinational firms, local suppliers, and domestic firms. The headquarters of the multinational firms are located in the parent country and expand the scope of their operations by establishing foreign affiliates abroad. They own advanced technology (Ramondo(2009)) and provide their affiliates with intermediate goods needed for the production of final goods. The affiliates set up in the host country produce final goods by assembling intermediate goods and support host country's demand. The other two agents, local suppliers and domestic firms are host country firms, and the local suppliers are in upstream and the domestic firms are in downstream industries, respectively. The local suppliers produce intermediate goods and provide them to several firms including both foreign affiliates and domestic firms in the downstream industry. Lastly, the domestic firms are in the same industry as the multinational firms and produce final goods by sourcing intermediate goods from local suppliers or for themselves. The structure of the model is described in figure 1.

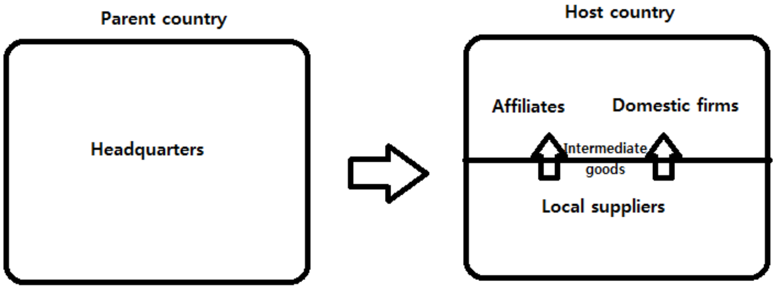

Figure1. Structure of the Model

The final goods, produced by foreign affiliates in the host country, are completed from an assembly of a range of intermediate goods. Each of the intermediate goods can either be sourced from parent firms by being shipped from the home country or be provided by local suppliers within the host country. In other words, some intermediate goods are produced in the parent country and the other intermediate goods are produced in the host country, and they are combined into one final good. When the intermediate good is produced in the host country, the technology needed to produce the intermediate good has to be transferred to its producers in the host country from the multinational firms. The technology transfer necessarily involves some errors because of incomplete communication between them. It makes host production less efficient than home production, and the loss of efficiency in the production of intermediate goods is called technology transfer cost. On the other hand, when the intermediate goods are produced in the parent country, there is no loss of efficiency in the intermediate goods production, but the goods have to be delivered to the affiliates abroad, incurring a shipping cost. Therefore, the multinational firms have to decide the location of production of intermediate goods by comparing the technology transfer cost and the shipping cost.

The intermediate goods vary in technological complexity, from simple to complex intermediate goods. Complex intermediate goods are less likely to be completely described in the manual or in the face-to-face communication. Even a very detailed manual cannot cover all the cases of various production environments of the complicate intermediate goods. Consequently, a large loss of efficiency in the complex goods production process accrues, requiring higher technology transfer costs than shipping costs. Therefore, multinational firms minimizing production cost decide to produce complex intermediate goods at home and then export those goods to their affiliates abroad. On the other hand, technologically simple intermediate goods generate small errors in transferring related knowledge, resulting in lower technology transfer costs than trade costs. Hence, the simple intermediate goods are sourced within the host country, incurring technology transfer costs.

Now, let's think about the mechanism of the knowledge spillovers and look at how the multinational firm's decision on the intermediate goods works in the mechanism. I provide an explicit mechanism of the horizontal knowledge spillovers by combining vertical spillovers which is already strongly supported in the previous literature.

As mentioned previously, since the multinational firms are large in size and have advanced technology, their entry to the host country may accompany technology diffusion to the domestic firms through various channels, such as worker turnover, product imitation, or vertical linkages. Among them, the knowledge spillovers through vertical backward linkages have been proved by several papers such as Javorcik(2006) and Kugler(2006). Also, anecdotal evidence introduced in Javorcik(2004b) confirms vertical knowledge spillovers. When a Czech firm producing aluminum alloy castings and supplying them to the automotive industry made a contract with a multinational firm, technicians of the multinational firm regularly visited the Czech firm to teach them how to improve quality control. Afterward, the Czech firm applied these improvement to its other production management. Indeed, the multinational firms may directly transfer their new technology to the local suppliers to meet their high standards for the product quality or to source intermediate goods at lower prices.

With the vertical knowledge spillovers and the fact that local suppliers usually make contracts with several firms in the downstream industry including both foreign affiliates and domestic firms and provide intermediate goods to them, we can infer that advanced technology of the multinational firms are delivered first to the local suppliers and then to the domestic firms in the same industry with the foreign affiliates. Namely, the high quality intermediate goods produced by local suppliers according to the multinational firm's new technology are provided to the foreign affiliates as well as domestic firms, and thus the domestic firms can take advantage of the more efficient intermediate goods from the entry of foreign affiliates. The intended diffusion of the knowledge between multinational firms and local firms on the first stage of the mechanism is called technology transfer, and the inadvertent diffusion in the second step of the mechanism is called knowledge spillovers. This is graphically shown in figure 2.

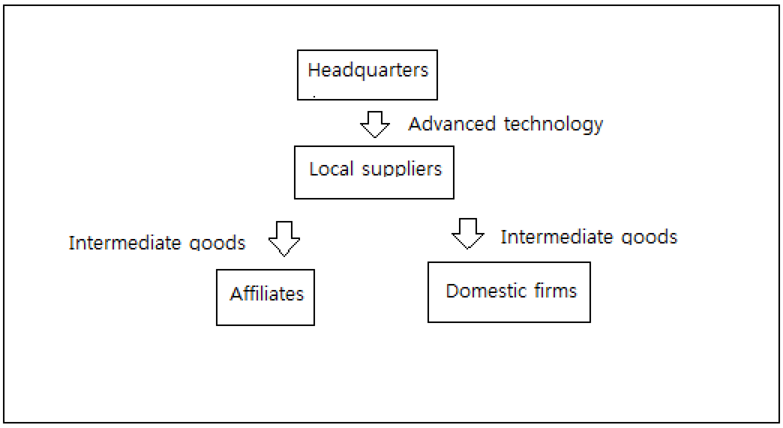

Figure 2. Mechanism of the Technology Transfer

Combining the decision of the multinational firms on the production location of the intermediate goods and the mechanism of the knowledge spillovers leads to different implications in high- and low-tech sectors. First, since high-tech sectors use more technologically complex intermediate goods to produce their final goods, and the complex intermediate goods generate expensive technology transfer costs, multinational firms decide to bring a large portion of intermediate goods from the home country to avoid the high transfer cost. Considering the mechanism of the knowledge spillovers, fewer contracts are made between multinational firms and local suppliers in the high-tech industries, leading to less vertical knowledge spillovers, to less intermediate goods produced according to the foreign firm's modern technology, and to less horizontal knowledge spillovers. On the contrary, since low-tech sectors mostly use simple intermediate goods which have lower technology transfer costs, multinational firms purchase more intermediates goods within the host country paying the technology transfer cost. It implies large knowledge transfers from the multinational to the local suppliers and more adoption of advanced intermediate goods by domestic firms. To summarize, knowledge diffusion through multinational firms is more active in the low-tech industry due to the cheaper technology transfer cost and more connection between foreign clients and the domestic suppliers. On the contrary, the knowledge spillovers in the high-tech industry are small because of the expensive technology transfer cost and less interaction between foreign and domestic firms.

Thus far, we have discussed knowledge spillovers at a fixed technology transfer cost. Now, let's consider the knowledge spillovers in a dynamic of the cost. As the technology transfer cost decreases due to some changes in the global environment, it has different impacts on the high- and low-tech industries. First, high-tech sectors are largely affected by the decline in the technology transfer cost because they have largely relied on home production. The home production of the complex intermediate goods can be moved to the host country, followed by more contracts between foreign firms and the local suppliers and continuous knowledge transfer from the foreign to the host firms. On the contrary, low-tech sectors are not significantly affected by the decline in the technology transfer cost because most of their technologically simple intermediate goods are already produced in the host country and they do not have much complex intermediate goods which benefit from the change in the technology transfer cost. As a results, no additional backward linkages are created and also no further knowledge spillovers occur. In sum, the knowledge spillovers are expected to be slow but continuous in the high-tech industries, but rapid and unsustainable in the low-tech industries.

3.2. **The Model.** This section provides more details on this framework. Consider a world which consists of two countries, parent country and host country. Each country is endowed with L units of labor, which is one of the input factors in the production of goods. In each country, the representative consumer has homothetic preferences over a variety of goods produced in the high- and low-tech sectors and a single homogeneous good Y as the following:

$$U = \Phi_h\, ln(\int_{\omega\in\Omega_h} q_h(\omega)^{\frac{\sigma_h-1}{\sigma_h}} d\omega)^{\frac{\sigma_h}{\sigma_h-1}} + \Phi_l ln(\int_{\omega\in\Omega_l} q_l(\omega)^{\frac{\sigma_l-1}{\sigma_l}} d\omega)^{\frac{\sigma_l}{\sigma_l-1}} + (1-\Phi_h-\Phi_l) lnY \cdots (1)$$

where Φ_h and Φ_l are the shares of expenditures spent for goods produced in high- and low-tech sectors, Ω_h and Ω_l are sets of varieties available in the respective sectors, $q_h(\omega)$ and $q_l(\omega)$ are the quantities of the output of the variety ω consumed, $\sigma_h > 1$ and $\sigma_l > 1$ are the elasticities of substitution across varieties in high- and low-tech sectors, and Y is the quantity of the homogeneous good consumed. Each country produces a homogeneous good using a single unit of labor, which means wages in both countries are the same and can be normalized to unity. Assuming that firms are too small to affect industry level demands, equation (1) implies the following iso-elastic demand function:

$$q_h(\omega) = \frac{\Phi_h}{P_h}(\frac{p_h(\omega)}{P_h})^{-\sigma_h}, \;\; q_l(\omega) = \frac{\Phi_l}{P_l}(\frac{p_l(\omega)}{P_l})^{-\sigma_l} \cdots (2)$$

where $p_h(\omega)$ and $p_h(\omega)$ are the prices of the variety ω in high- and low-tech industries, and P_h and P_l are the aggregate prices defined as $P_h \equiv \int_{\omega \in \Omega_h} p_h(\omega)^{1-\sigma_h} d\omega$ and $P_l \equiv \int_{\omega \in \Omega_l} p_l(\omega)^{1-\sigma_l} d\omega$ in respective sectors.

Each firm produces a different variety of differentiated goods by assembling a continuum of intermediate inputs according to the following production function:

$$x_i = A_i L_i^{\alpha} [\int_0^{\infty} \beta_i m_i(z) dz]^{1-\alpha} \cdots (3)$$

where z is an index of technological complexity of an intermediate good, $m_i(z)$ is the quantity of an intermediate z used in the production, and β_i is a stock of knowledge of the intermediate good. I will distinguish β_i^D and β_i^F as the domestic and foreign stock of knowledge later in the paper.

Let's assume that intermediate goods composition function, $m_i(z)$, has the following functional form:

$$m_i(z) = \phi_i exp(-\phi_i z) \cdots (4)$$

The firms which use more technologically complex intermediate goods to produce a final good have higher value of $m_i(z)$ for higher z, classifying them as high-tech industries. On the other hand, low-tech industries use less technologically complex intermediate goods in producing their final goods and it comes with lower $m_i(z)$ for higher z. The advantage of this functional form is that an average technological complexity of firm i can be summarized by one parameter, as an inverse of ϕ_i. That is, firms in the high-tech industry have low values of ϕ_i while low-tech firms have high values of ϕ_i.

The multinational firms open their affiliates abroad and the foreign affiliates produce final goods according to the production function above. The headquarters of the multinational firms must make a decision from where each intermediate good is sourced to their affiliates. Each intermediate good can be provided either by parent firms from the home country or by local suppliers within the host country, accompanying trade costs or technology transfer costs, respectively.

In the case that the intermediate goods are produced by headquarters in the parent country, no loss of efficiency is incurred in the production of intermediate goods but shipping costs to deliver the intermediate goods internationally are incurred. The shipping cost is assumed to take the iceberg form, which is widely used in the international economics literature: $\tau > 1$ units must be shipped in order for one unit to arrive at the host country. The parameter τ is assumed to be constant regardless of the intermediate good.

On the other hand, the latter case, the procurement of intermediate goods from local suppliers, incurs some loss of efficiency in the production of intermediate goods instead of trade cost because there may be some errors in the communication between headquarters and local firms. Let $\lambda\tilde{(t)}$ be the probability of successful communication between headquarters and local suppliers. It naturally takes values between 0 and 1. The probability is independent of the intermediate goods but it depends on the circumstances in which the international communication takes place. The condition describes how easily and correctly the communication between headquarters and local suppliers is taking place. It indicates all economic and social barriers of domestic sourcing involving availability of high-skilled workers in the host country, geographic distance between home and host country, or development of the skill describing a blueprint of the intermediate good. It is simply summarized by a single parameter of t and it is applied for all intermediate goods. It varies over time. For instance, as the number of high-skilled workers in the host country increases, local firms may become more efficient at absorbing advanced technology delivered by foreign firms and thus decrease possible errors in the production of intermediate goods. Also, as airfares decrease, it may increase the chance of face-to-face communication, eliminate distorted communication between headquarters and local suppliers, and so the technology transfer cost may decrease. The change of the communication circumstances affects all intermediate goods.

Based on the assumption for general probability of successful communication, each specific intermediate good's perfect communication probability can be expressed as $\tilde{\lambda(t)}^z$. Since $\tilde{\lambda(t)}$ is between 0 and 1, the higher z of a more complex intermediate good implies more failure for the successful communication of the required knowledge. It also can be expressed with a large number of labor units needed to produce the goods as the following after some simple algebra:

$$\frac{1}{(\tilde{\lambda(t)})^z} = exp(-zln(\tilde{\lambda(t)}) = exp(\lambda(t)z) \quad where\ \lambda(t) \equiv -ln(\tilde{\lambda(t)}) \cdots (5)$$

It is called the technology transfer cost for the intermediate good z. The technology transfer cost for a specific intermediate good depends both on the circumstances in which the communication is taking place and the technological complexity of the intermediate good. For instance, the technology transfer cost of the complex intermediate goods in unfavorable communication circumstances is very high.

The cost-minimizing multinational firms determine the location of the production of the intermediate goods by comparing trade cost and technology transfer cost. The marginal cost of the intermediate good depends on the location where it is produced as given by:

$$c(z) = \begin{cases} \tau & if\, imported\, from\, parent\, firms \\ exp(\lambda(t)z) & if\, produced\, by\, local\, suppliers \end{cases} \cdots (6)$$

The trade cost is not intermediate good specific, but the technology transfer cost depends on the technological complexity of the intermediate good, increasing with the knowledge intensity of the intermediate good. From the equation (6), we can obtain a cutoff intermediate input, $\hat{z(t)}$, at which trade cost and technology transfer cost are equated as given by:

$$\hat{z(t)} = \frac{1}{\lambda(t)} ln(\tau) \cdots (7)$$

All intermediate goods with z less than the cutoff level $\hat{z(t)}$ have lower technology transfer costs than shipping costs and are thus sourced to the affiliates within the host country, while all intermediate goods with z higher than $\hat{z(t)}$ incur higher technology transfer cost than trade cost and thus are delivered to the affiliates from the parent country.

Combining the intermediate goods composition function, $m(z)$, and the cutoff level of the technological complexity of the intermediate inputs, $\hat{z(t)}$, makes it possible to obtain the total quantity of intermediate goods procured in the host country by integrating the intermediate input function up to $\hat{z(t)}$:

$$H = 1 - exp(-\phi_i \hat{z(t)}) \cdots (8)$$

This is shown in the figure 3 as the area under the exponential function up to $\hat{z}$.

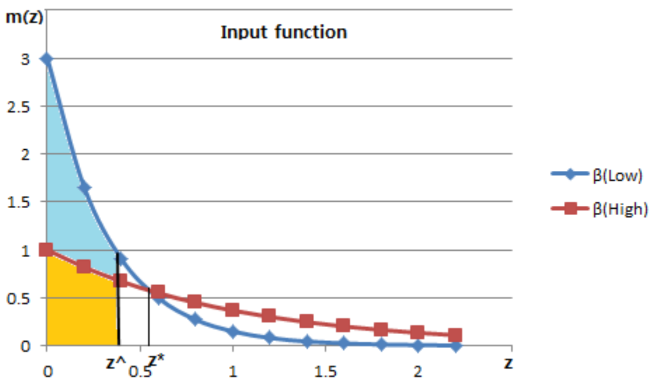

Figure 3. Intermediate Goods Composition Function for High and Low-tech industries

Since an average complexity of the intermediate goods is higher in the high-tech industries than that in the low-tech industries, as mentioned previously, it is summarized in a single parameter as a lower ϕ for the high-tech and a higher ϕ for the low-tech industries. Therefore, in the figure above, the high-tech industry is represented by a smoothly decreasing curve while the low-tech industry by a curve with a steep slope. In terms of the host country sourcing of the intermediate goods, it is larger for the low-tech industries because host production is cheaper than home production for simple goods, whereas local purchase of high-tech foreign firms is smaller to avoid expensive technology transfer costs. This is supported by data. The figure 4 shows the share of intermediate goods shipped to the affiliates from their parent company in total sales in the automobile and food industries, which represent high- and low-tech sectors, respectively. The automobile industry brings more intermediate goods from the parent country, implying less sourcing within the host country, while food industries import less intermediate goods, implying more purchase from the local suppliers.

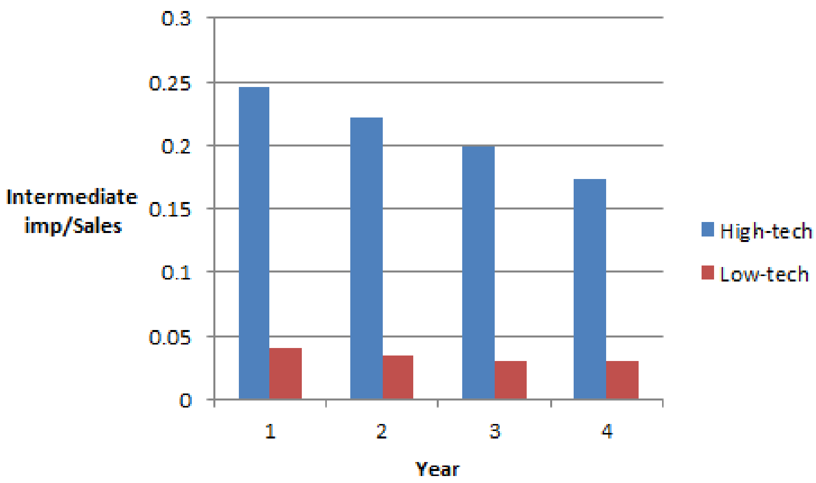

Figure 4. Intra-Firm Imports Shares in Automobile and Food Industries

Now, let's turn to the mechanism through which a foreign firm's modern technology is diffused in the host country. In order to explicitly describe the extent to which foreign advanced technology have impacts on the domestic firm's productivity, I compare the domestic firm's total output in the absence and presence of the multinational firms in the host country. Before proceeding to the comparison, let's recall the stock of knowledge for intermediate goods. As previously mentioned, I would distinguish domestic and foreign knowledge stocks for intermediate goods. For the simplicity, it is assumed that the domestic and foreign knowledge stocks are constant for all intermediate goods, implying that domestic and foreign stocks of knowledge differs by the same amount for all intermediate inputs. Also, the foreign knowledge stock is assumed to be higher than the domestic knowledge stock, which is consistent with the fact that multinational firms are generally large and own advanced technology. The higher stock of knowledge means that the intermediate good is more efficiently used in the production process and it will increase the quantity of output produced. The assumptions can be summarized as the following:

$$\beta_F = \gamma,\ \ \beta_D = \delta,\ \ \beta_F - \beta_D > 0\ \ for\, all\, z \cdots (9)$$

First, if there is no presence of the multinational firms in the host country, the domestic firms produce their final goods by assembling intermediate goods produced relying fully on the domestic knowledge stock:

$$Y_D = AL^{\alpha}[\int_0^{\infty} \beta_D m_i(z)dz]^{1-\alpha} \cdots (10)$$

where Y_D is domestic firm's output, β_D is domestic knowledge stock of the intermediate goods, and the rest of the parameters are the same as those introduced in the production function.

Second, if multinational firms enter the host country, open their affiliates and make contracts with local suppliers to purchase intermediate goods, technology transfer arises through backward linkages, local suppliers produce intermediate goods with better quality, and domestic firms have access to the high quality intermediate goods. However, it is only applied for the intermediate goods which have lower technology transfer costs than trade costs and thus sourced to the affiliates within the host country. The domestic firm's output in the presence of the multinational firms is expressed as the following:

$$Y_D = AL^{\alpha}[\int_0^{\hat{z}} \beta_F m_i(z)dz + \int_{\hat{z}}^{\infty} \beta_D m_i(z)dz]^{1-\alpha} \cdots (11)$$

where β_F represents foreign knowledge stock. The domestic firms produce final goods by assembling new simple intermediate goods with better quality and existing more complex intermediate goods. Since β_F is larger than β_D by assumption, output of the domestic firms in the presence of multinational firms is larger than that in the absence of them.

I will first consider the positive effect that the domestic firms gain from the multinational firms, called knowledge spillovers, in the case in which the general probability of communication, $\lambda(t)$, is fixed, and then investigate it in the case where it decreases due to the improvement in the communication environment between foreign and local firms.

The knowledge spillovers in the former case, can be calculated by subtracting equation (10) from the equation (11). For the simplicity, let $\int_0^\infty \beta_D m_i(z)dz$ be M. Then, it is as the following:

$$\triangle Y_D = AL^\alpha\{[(\beta_F - \beta_D)H + M]^{1-\alpha} - M^{1-\alpha}\} \cdots (12)$$

where H comes from the equation (8) and it indicates the total amount of the intermediate goods purchased by foreign affiliates within the host country. Since H_l, for the low-tech industry, is larger than H_h, for the high-tech industry, the knowledge spillovers is larger in the low-tech industry than those in the high-tech industry.

Turning to the dynamic patterns of the knowledge spillovers, let's consider how they are changing as technology transfer cost decreases. When the technology transfer cost decreases, the production of complex intermediate goods moves from the home to the host country. In the model, the cut-off level of intermediate goods, $z(\hat{t})$, moves to the right and host production, H, increases, as shown in the equation (7) and (8), and it is described in the figure 5. Due to the downward movement of the technology transfer cost, the range of intermediate goods of host sourcing is extended, and total amount of intermediate goods purchased within the host country rises. It implies additional contracts of the multinational firms with the local firms and accordingly expanded channel of the technology transfer.

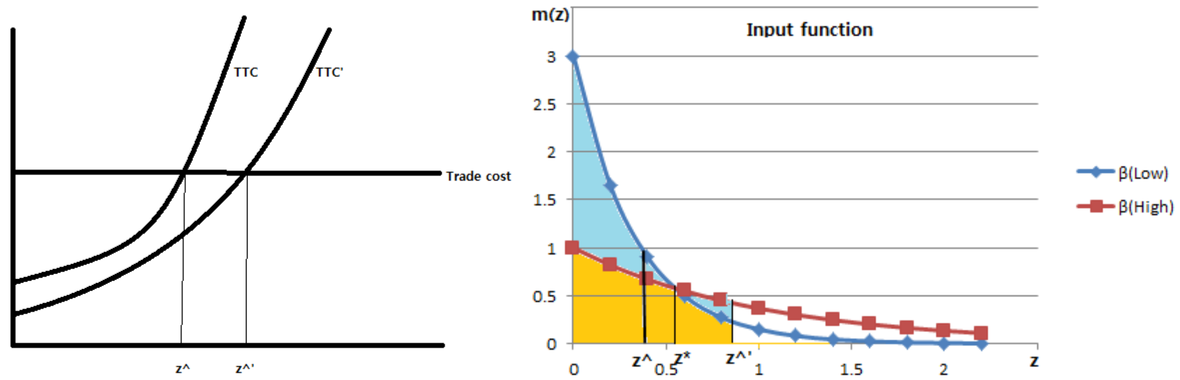

Figure 5. The Impact of the Reduction in TTC on the Cut-off Level of Intermediate Good and Local Sourcing

Following the reduction in technology transfer cost, its marginal effect on the domestic output is mathematically shown as given:

$$\frac{\partial(\triangle Y_D)}{\partial \hat{z}} = AL^{\alpha}(1-\alpha)[(\beta_F-\beta_D)(1-exp(-\phi_i\hat{z}))+M]^{-\alpha}(\beta_F-\beta_D)\phi_i exp(-\phi_i\hat{z}) \cdots (13)$$

There are two important points that we can infer from the equation (13). First, the marginal increase in domestic output decreases in $\hat{z}$. The decrease in the technology transfer cost at its sufficiently high level has small impact on the local firms' productivity. It is entirely because of the decreasing intermediate goods composition function. Actually, it may be that it is more reasonable to assume that the intermediate goods composition function for the high-tech industries is increasing with respect to the complexity of the intermediate goods. That is, their use of intermediate goods is concentrated on the complex intermediate goods. Even in this case, since the fact that low-tech industries use relatively more technologically simple intermediate goods than high-tech industries, the main conclusion of the model is not affected. Second, more importantly, the equation (13) allows us to observe different behavior of the knowledge spillovers in each sector. To lay out these explanations precisely, let's first compare the equation (13) for high- and low-tech industries. Let an intersection of the intermediate goods composition function for high- and low-tech sectors be z*, as shown in the figure 3.

$$exp(-\phi_l \hat{z}) > exp(-\phi_h \hat{z}) \ for \ \hat{z} < z* \Rightarrow (\frac{\partial(\triangle Y_D)}{\partial \hat{z}})_L > (\frac{\partial(\triangle Y_D)}{\partial \hat{z}})_H \ for \ \hat{z} < z* \cdots (14)$$

$$exp(-\phi_h \hat{z}) > exp(-\phi_l \hat{z}) \ for \ \hat{z} > z* \Rightarrow (\frac{\partial(\triangle Y_D)}{\partial \hat{z}})_H > (\frac{\partial(\triangle Y_D)}{\partial \hat{z}})_L \ for \ \hat{z} > z* \cdots (15)$$

The marginal impacts of the technology transfer cost on the domestic firm's productivity are reversed once at the intersection, z*, for low-tech industries from higher to lower impacts and for high-tech industries from lower to higher impacts.

When the communication between foreign and local firms are not efficient and thus simple intermediate goods are only sourced from local suppliers, the low-tech industries which mostly use simple intermediate goods establish considerable connection with local firms and then large channels of technology transfer. On the other hand, under the circumstances of the inefficient communication between foreign and local firms, high-tech industries bring most of the intermediate goods from their parent companies, making a limited interaction with local suppliers and thus restricted technology transfer channels. However, as an environment of the technology communication between foreign and local firms has improved, complex intermediate goods' production has moved from the parent to the host country, expanding technology transfer channels, in particular, in high-tech industries which use more complex goods in their production. To summarize, interpreting it in terms of the host firms, low-tech sectors achieve the advanced level of multinational firm's technology shortly, and there is no longer increases in spillovers ever since the full achievement of the new technology. On the other hand, the domestic firms in the high-tech sectors do not immediately experience a vast knowledge transfer from foreign firms, but they continually benefit from the decline in technology transfer cost and gain productivity growth.

It is shown in the figure 6 in which the horizontal axis represents a reverse of the technology transfer cost or the extent to which multinational firms interact with the local firms, and the vertical axis stands for the productivity of the domestic firms. Here, multinational firm's technology is standardized to 1 on the vertical axis.

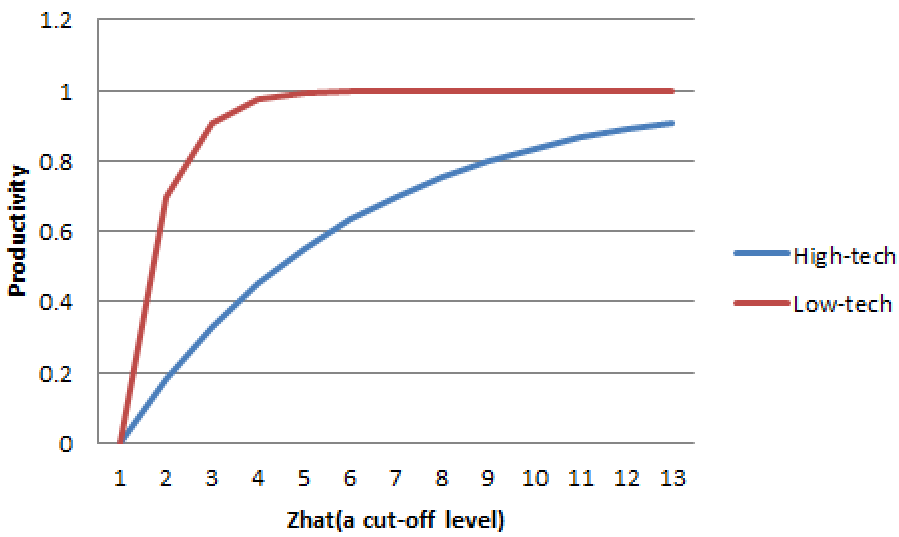

Figure 6. The Patterns of Knowledge Spillovers in High- and Low-tech industries

This section has laid out the model which explains the mechanism of the knowledge spillovers from multinational firms and its different patterns in the high-tech and low-tech sectors. The next section look at the data and investigate whether the model is supported by the data.

4. Data and Methodology

4.1. **Methodology.** Most of the previous literature has tested whether the productivity of the domestic firm is growing faster in industries in which multinational firms are actively operating, in the form of a linear relation of domestic firm's productivity and foreign presence in the industry to which the domestic firm belongs. This study is markedly contrasted to them in the way that it looks at how the domestic firm's productivity is affected by the change in technology transfer cost or the extent to which multinational firms have linkages with the local firms, not foreign firm's share in the same industry. Furthermore, it is tested in the form of a quadratic equation, which allows for a possibility of diminishing marginal impacts of the technology transfer cost on the productivity as laid out in the previous section. The following regression equation is estimated:

$$tfp_{ijt} = \beta_1 X_{ijt} + \beta_2 \hat{z}_{jt} + \beta_3 \hat{z}_{jt}^2 + \varepsilon_{ijt} \cdots (16)$$

where tfp_{ijt} is the productivity of the domestic firm i in industry j at time t, $\hat{z}$ is the cut-off level at which technology transfer cost and trade cost of the intermediate good are equated, X is a set of control variables, and ε_{ijt} is a mean-zero error term.

The model says that the reduction in the technology transfer costs has different impacts on the productivity of the domestic firms in the high-tech and low-tech industries. The technology transfer from multinational firms is initially very large in the low-tech industry, but it does not continue as domestic firms become able to perfectly imitate the advanced technology of the foreign firms. In contrast, the technology transfer is small in the high-tech industries but it persistently takes place as the technology transfer cost decreases. If the data is consistent with the conclusion of the model, the coefficient on $\hat{z}$ should be positive in both sectors, but small in the high-tech and large in the low-tech sectors. Also, the coefficient on $\hat{z}^2$ should be negative in both sectors, but small in absolute terms in the high-tech and large in the low-tech sectors.

One of the main interesting variables in this equation is $\hat{z}$. However, it is unobserved and difficult to directly measure from the data. Fortunately, equation (8) can be solved for $\hat{z}$ to attain:

$$\hat{z} = -\frac{1}{\phi_i} ln(1 - H) \cdots (17)$$

$1 - H$ in equation (17) corresponds to the total intermediate goods imported to the foreign affiliates from their parent company, a variable that can be observed. As a result, $\hat{z}$ can be determined from the data on imports of intermediate goods from the headquarters to the affiliates.

Also, the domestic firms' productivity is the focus of this paper and thus the consistent estimation for the estimates is crucial. The productivity of the domestic firms are carefully measured by the Olley-Pakes method. Since OLS does not take into account the fact that production inputs may be chosen by firms based on their productivity, it may involve a simultaneity problem and generate biased estimates. Also, OLS does not consider entry and exit of firms. The Olley-Pakes method deals with these problems by developing a framework in which firms optimally choose investment and sales and also make entry and exit decisions, thus resolving these problems. The table 1 presents a comparison of the estimation results of OLS and Olley-Pakes(OP) method. The smaller O-P coefficients on labor and materials and a larger O-P coefficient on capital than OLS estimates, confirm that Olley-Pakes method corrects for the biases.

Input factors	OLS	OP
Capital	0.096	0.115
Labor	0.519	0.516
Materials	0.413	0.398
Scale Elasticity	1.028	1.029

Table 1. OLS and Olley-Pakes Input Elasticity Estimates

With Olley-Pakes input elasticity estimates calculated above, we can compute total factor productivity by the following Cobb-Douglas production function:

$$tfp_{it} = y_{it} - \beta_k^{OP} k_{it} - \beta_l^{OP} l_{it} - \beta_m^{OP} m_{it} \cdots (18)$$

where y_{it}, k_{it}, and m_{it} stand for the logarithm of output, labor, and material inputs, respectively, and β_k^{OP}, β_l^{OP}, and β_m^{OP} are the Olley-Pakes estimates for the elasticities of output with respect to capital, labor, and materials.

In order to better isolate the FDI spillovers through the mechanism introduced in the model, I consider several control variables that may influence local firms' performance. First, R&D expenditure and a ratio of capital to labor are included because they may impact firms' productivity and foreign firms' activities in the host country, and thus may cause biased estimates. Also, an index for industry concentration, the Herfindahl-Hirschman Index(HHI), are considered as one of the control variables. It is because that the entry of the foreign firms may increase competition with domestic firms, forcing domestic firms to improve their efficiency.

4.2. **Data.** The empirical analysis is based on U.S. manufacturing firms for the years of 1987 through 1995, taken from Standard and Poor's Compustat database. It includes publicly traded firms; more importantly, most large U.S. firms. As a result, it covers most U.S. economic activity. The sample consists of about 1,000 firms and it is further reduced by deleting those that have missing values or fail to satisfy some standard criteria. Compustat provides the firm-level data needed to calculate productivity such as output, labor, capital, and materials. It also offers data on R&D expenditure. First, the output is measured by net sales from Compustat, and it is deflated by industry-level price index from the NBER-CES manufacturing database. Labor is measured by total working hours which is the number of employees from Compustat multiplied by industry-level average production working hours from the NBER-CES manufacturing database. Capital is measured by the value of property, plant and equipment, net of depreciation from Compustat, and it is deflated by deflators from the BEA satellite accounts. Lastly, materials follow the definition of cost of goods sold plus administrative and selling expenses less wage expenditures, where the wage is calculated by multiplying the number of employees with the average industry wage. The former two variables come from Compustat, while the latter is obtained from the NBER-CES manufacturing database. The R&D expenditure and capital-labor ratio, used as control variables in the empirical estimation, also comes from Compustat. R&D expenditure is obtained by deflating research and development expenses from Compustat by deflators from the BEA satellite accounts, and the capital-labor ratio is obtained by dividing capital calculated above by the number of employees. The other control variable, the Herfindahl-Hirschman Index(HHI), is obtained from BEA and it is transferred from SIC to ISIC Rev.3 using SIC and ISIC Rev.3 matching table published by Princeton University.

The main purpose of this paper is to examine whether productivity of the domestic firm is affected by the change in the technology transfer cost and whether it behaves differently in high- and low-tech sectors. As explained above, the change in technology transfer cost is reflected in the cutoff-level of intermediate goods, and it is measured by equation (17) and data on intra-firm imports. The OECD provides data on the activities of the multinational firms from a wide range of perspectives in their series of 'Measuring globalization'. In particular, they provide data on intra-firm imports, value-added, and sales of the foreign affiliates operating in OECD countries. For the U.S., since the data on the sales of the foreign affiliates are not available, $1 - H$ is measured by the ratio of the intra-firm imports to the value-added and then $\hat{z}$ is calculated using the equation (17). Since the OECD data is classified by ISIC Rev.3 and the firm-level data from Compustat use NAICS, I convert NAICS into ISIC Rev.3 referring to correspondence table published by the United Nations Statistics Division in order to raise compatibility between the OECD and the Compustat data.

In order to investigate the main question related to the different patterns of knowledge spillovers in the high- and low-tech industries, the full sample is divided into two groups, according to the share of R&D expenditures in total sales averaged across firms in the same industry. The group with high shares of R&D expenditures is classified as high-tech, and the group with low ratio of R&D expenditures in total sales as low-tech. The intra-firm import shares are 60.14 and 30.39 percentage for high- and low-tech industries, respectively. The high-tech industries include chemical products, radio, TV & communication eq., office and computing machinery, wood products, scientific instruments, non-electrical machinery nec, and motor vehicles, while the low-tech industries cover food, beverages, tobacco, non-metallic mineral products, paper, printing, and publishing, textiles, clothing, leather, and footwear, electrical machinery nec,basic metals, other transport equipment, and other manufacturing, and fabricated metal products.

5. Results

This section presents the results of the paper. First, I show some features of the main variables, in particular, technology transfer cost. Second, I lay out the main results of estimating the main empirical estimation equation, provide an interpretation of coefficients, and see whether it is consistent with the model or not. Lastly, I reestimate variants of the main equation to check the robustness of the results.

The technology transfer cost is measured by equation (17) using data on imports shipped to foreign affiliates from their parent company. The table 2 lists industries ranked by shares of imports delivered from their headquarters in total value added. It ranges from about 11 percent in paper, printing, and publishing to over 210 percent in office and computing machinery. As expected in the model, low-tech industries such as food, beverages, or textiles import relatively less from their parent companies. In contrast, high-tech industries such as motor vehicles or computing industry bring more inputs from their parent company.

Industries	Imports/value added
Paper, printing and publishing	11.10174
Non-metallic mineral products	15.29116
Scientific instruments	22.6695
Textiles, clothing, leather, footwear	25.22104
Food, beverages, tobacco	25.50008
Other manufacturing	26.19165
Fabricated metal products	26.79906
Chemical products	26.83764
Wood Products	31.89393
Other transport equipment	38.36132
Rubber and plastics products	41.73578
Electrical machinery nec	51.39014
Basic metals	52.43902
Non-electrical machinery nec	66.34168
Radio, TV & communication eq.	113.496
Motor vehicles	187.6598
Office and computing machinery	261.4654

Table 2. Intra-Firm Imports by Industry, in percent of value added

The model shows the positive non-relationship between productivity of the domestic firms and the extent to which multinational firms are connected to the host firms. Also, the model predicts different patterns of productivity changes in high-tech and low-tech industries based on their technological complexity of the intermediate goods. The raw data shows how they are correlated in the following graph.

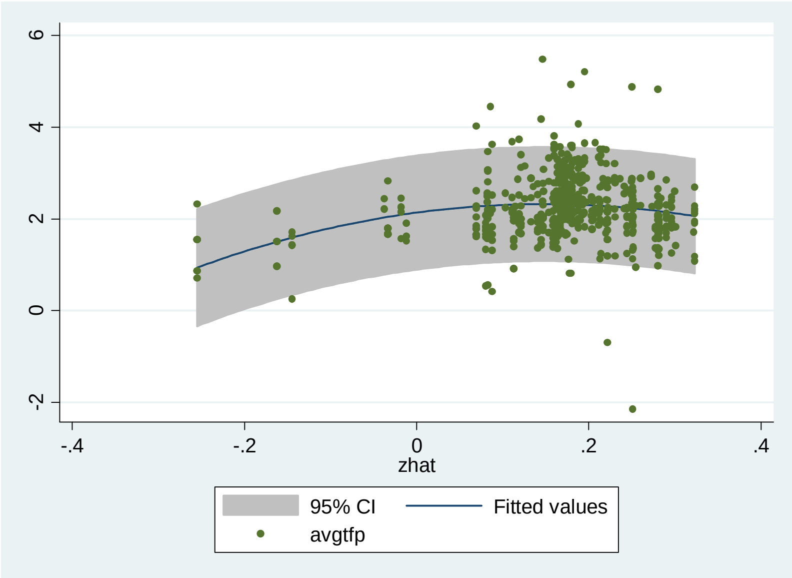

Figure 7. Domestic Productivity and Technology Transfer Cost

The horizontal axis represents cut-off level of intermediate goods and the vertical axis stands for productivities of the domestic firms. The figure 7 provides an evidence that the productivities of the domestic firms increase as technology transfer cost decreases, and they are nonlinearly related, rather than the linear association mostly assumed in the previous literature.

Before proceeding to see the main results, I examine whether the increasing convex shape fits the data better than the linear one. In order to do so, I compare the regression results obtained under the assumption of the linear and curvilinear forms, respectively. As indicated by the adjusted R-squares at the bottom of the table 3, the curvilinear functional form fits better the data than the linear one. Also, an F-test in which the linear specification is treated as a restricted equation of the full model shows that the quadratic term has some power to explain the association of the technology transfer cost and domestic firms' productivity at the 1% level of significance.

	(1) Linear	(2) Quadratic
R&D	-0.00333	-0.00307
	(0.00186)	(0.00190)
Capital_Labor	0.000102	0.000314*
	(0.000121)	(0.000120)
HHI	0.000546***	0.000719***
	(0.000149)	(0.000133)
Zhat	-0.0776	0.752*
	(0.390)	(0.363)
(Zhat)^2		-7.510***
		(1.442)
Constant	2.749***	2.745***
	(0.117)	(0.0993)
r2	0.0397	0.0987
F	7.386	11.69

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.05, ** p<0.01, *** p<0.001

Table 3. The comparison of Linear and Curvilinear Functional Form

Table 4 reports the main results. The dependent variable, total factor productivity for firm i in sector j at time t measured by Olley-Pakes method, is regressed on the cut-off level of the intermediate goods in sector j at time t in a quadratic function. The standard errors are clustered by industry-year combinations because firms in the same industry j encounter the same intra-firm imports and thus the same cut-off level of the intermediate goods in a given year.

The first column in the table 4 shows OLS results for the full sample of firms. The coefficient on the cut-off level of the intermediate goods is positive and statistically significant and the coefficient on its square is negative and statistically significant, suggesting that there are productivity gains associated with the decrease in the technology transfer cost but the marginal gains diminish as the technology transfer costs decrease. The point estimate for zhat, 0.752, shows that productivity of the domestic firms would increase by 7.52 percentage points when the cut-off intermediate good moves to the right by 10 percent.

	(1) Total	(2) High-Tech	(3) Low-Tech
R&D	-0.00307	-0.000485	-0.00606**
	(0.00190)	(0.00210)	(0.00298)
Capital_Labor	0.000314**	0.000228	0.000393
	(0.000120)	(0.000154)	(0.000467)
HHI	0.000719***	0.000802***	0.000561***
	(0.000133)	(0.000209)	(0.000191)
Zhat	0.752**	0.879*	11.08***
	(0.363)	(0.464)	(3.967)
(Zhat)^2	-7.510***	-8.634***	-32.09***
	(1.442)	(2.037)	(10.38)
Constant	2.745***	2.732***	1.843***
	(0.0993)	(0.135)	(0.340)
Observations	427	230	197
Adjusted R-squared	0.088	0.090	0.098

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.10, ** p<0.05, *** p<0.01

Table 4. Impact of Technology Transfer Cost on the Productivity of the Domestic Firms

The next two columns present results for the subsamples of firms, divided into the high- and low-tech industries. For both sectors, the coefficients on the cut-off level of intermediate goods are positive and statistically significant, and the coefficients on its square are negative and statistically significant. These results clearly show curvilinearity in the relationship between the technology transfer cost and domestic firms' productivity. However, the magnitude of the coefficients are quite different in the two sectors. The coefficient on zhat is much larger for low-tech industries, supporting an immediate catch-up to the foreign firms' advanced technology in the low-tech industry. On the other hand, the zhat coefficient for high-tech industries is small, implying a slow catch-up to the foreign firms' technology. These are consistent with the results expected in the model.

The coefficient on the square of zhat is much larger in an absolute term in the low-tech industries, providing large diminishing impacts of the technology transfer cost on the domestic productivity in the low-tech industries. Meanwhile, it in the high-tech industries is very small in an absolute term, pertaining to continuous productivity benefits of the domestic firms. These estimation results are also consistent with the model in the way that there are no longer technology transfer beyond some technology transfer cost in the low-tech industries, whereas high-tech industries continually benefit from the decrease in the technology transfer cost and thus there are continuous knowledge spillovers.

Turning to the control variables, coefficients on R&D expenditures appear to be negative and statistically significant, contrasting to the general expectations for the firms' R&D activities. The capital-labor ratio estimates are positive but they are statistically insignificant. Lastly, HHI estimates come in as expected, suggesting that a higher industry concentration compels firms to be more efficient.

In sum, the empirical findings are consistent with the model: an immediate knowledge spillovers but unsustainable increases in spillovers in the low-tech industries, while very slow knowledge spillovers but continuous spillovers in the high-tech industries.

The knowledge spillovers from foreign to domestic firms may take time to manifest themselves. In order to examine it, I reestimate the equation (16) taking one-year and two-year lagged spillovers variables. The table 5 through table 7 present the results for full, high-tech, and low-tech industries, respectively. For the purpose of comparisons, the tables include regression results with contemporaneous, one-year lagged , and two-year lagged spillovers variables in each column.

The coefficients on lagged variables for zhat and squared zhat remain positive and negative, respectively. With regard to the magnitudes of the coefficients on the lagged zhat and squared zhat, they do not change much, suggesting that the positive impact of the technology transfer cost on the domestic firms and diminishing marginal impact of the knowledge spillovers do not quickly vanish. However, the spillovers appear to be no longer statistically significant in two periods in the low-tech industries.

	(1) Current	(2) Lagged One	(3) Lagged Two
R&D	-0.00307	-0.00331	-0.00320
	(0.00190)	(0.00191)	(0.00184)
Capital_Labor	0.000314*	0.000343**	0.000304*
	(0.000120)	(0.000119)	(0.000126)
HHI	0.000719***	0.000741***	0.000740***
	(0.000133)	(0.000130)	(0.000140)
Zhat	0.752*		
	(0.363)		
(Zhat)^2	-7.510***		
	(1.442)		
Zhat_Lag1		0.838*	
		(0.341)	
Zhat^2_Lag1		-8.095***	
		(1.361)	
Zhat_Lag2			0.912*
			(0.348)
Zhat^2_Lag2			-7.657***
			(1.387)
Constant	2.745***	2.731***	2.707***
	(0.0993)	(0.0957)	(0.106)
Observations	427	416	408
Adjusted R-squared	0.088	0.093	0.081

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.05, ** p<0.01, *** p<0.001

Table 5. Results with Current, One-year Lagged, and Two-year Lagged Spillovers Variables for the Full Sample of Data

	(1) Current	(2) Lagged One	(3) Lagged Two
R&D	-0.000485	-0.000618	-0.00104
	(0.00210)	(0.00218)	(0.00203)
Capital_Labor	0.000228	0.000249	0.000214
	(0.000154)	(0.000153)	(0.000162)
HHI	0.000802***	0.000835***	0.000817***
	(0.000209)	(0.000203)	(0.000219)
Zhat	0.879*		
	(0.464)		
(Zhat)^2	-8.634***		
	(2.037)		
Zhat_Lag1		0.975**	
		(0.430)	
Zhat^2_Lag1		-9.097***	
		(1.886)	
Zhat_Lag2			1.032**
			(0.424)
Zhat^2_Lag2			-8.380***
			(1.886)
Constant	2.732***	2.704***	2.684***
	(0.135)	(0.128)	(0.146)
Observations	230	224	219
Adjusted R-squared	0.090	0.094	0.074

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.10, ** p<0.05, *** p<0.01

Table 6. Results with Current, One-year Lagged, and Two-year Lagged Spillovers Variables for High-tech Sectors

	(1) Current	(2) Lagged One	(3) Lagged Two
R&D	-0.00606*	-0.00651*	-0.00595
	(0.00298)	(0.00298)	(0.00305)
Capital_Labor	0.000393	0.000341	0.000301
	(0.000467)	(0.000478)	(0.000480)
HHI	0.000561**	0.000592**	0.000639**
	(0.000191)	(0.000195)	(0.000203)
Zhat	11.08**		
	(3.967)		
(Zhat)^2	-32.09**		
	(10.38)		
Zhat_Lag1		9.754*	
		(4.202)	
Zhat^2_Lag1		-29.75**	
		(10.96)	
Zhat_Lag2			6.625
			(4.660)
Zhat^2_Lag2			-21.62
			(12.07)
Constant	1.843***	1.983***	2.232***
	(0.340)	(0.377)	(0.419)
Observations	197	192	189
Adjusted R-squared	0.098	0.099	0.083

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.05, ** p<0.01, *** p<0.001

Table 7. Results with Current, One-year Lagged, and Two-year Lagged Spillovers Variables for Low-tech Sectors

In order to check the robustness of the results, I reestimate the main equation by replacing total working hours with total number of employees in the calculation of the productivity. The results are very similar with the previous one, suggesting that the results are robust to the measurement of the labor. The table 8 contains the results.

	High-tech (1) Hours	(2) EMP	Low-tech (3) Hours	(4) EMP
R&D	-0.000485	-0.000908	-0.00606**	-0.00708**
	(0.00210)	(0.00204)	(0.00298)	(0.00305)
Capital_Labor	0.000228	0.000228	0.000393	0.000513
	(0.000154)	(0.000152)	(0.000467)	(0.000474)
HHI	0.000802***	0.000832***	0.000561***	0.000568***
	(0.000209)	(0.000208)	(0.000191)	(0.000183)
Zhat	0.879*	0.899*	11.08***	10.97***
	(0.464)	(0.480)	(3.967)	(3.750)
(Zhat)^2	-8.634***	-8.568***	-32.09***	-31.90***
	(2.037)	(2.099)	(10.38)	(9.915)
Constant	2.732***	3.047***	1.843***	2.177***
	(0.135)	(0.136)	(0.340)	(0.310)
Observations	230	230	197	197
Adjusted R-squared	0.090	0.092	0.098	0.114

Standard errors in parentheses
zhat: a cut-off level of intermediate goods at which TTC and trade cost are equated.
* p<0.10, ** p<0.05, *** p<0.01

Table 8. Results with different measures of labor inputs

6. Conclusion

Even though economists and policy makers have devoted considerable attention to the effects of multinational firms on the productivity of the domestically-owned firms, they have not come to a common conclusion. It is due to the fact that knowledge spillovers by multinational firms in the host country are very complex, depending on various firm, industry, and country factors. Therefore, we need deeper understanding of FDI spillovers in various circumstances.

In contrast to the earlier literature, which focused on the total effects of multinational firms on the domestic firms' productivity, this paper considers the knowledge spillovers separately in high- and low-tech industries. Using a simple theory, I show that technological complexity of industries causes different knowledge spillovers by analyzing the endogenous decision of multinational firms on the location of production of intermediate goods. The model is supported by U.S. data for the years 1987-2005.

The model and empirical results coherently show that initial knowledge spillovers in the low-tech industries are very fast and large but there is no longer productivity gains once domestic firms catch up with the foreign firms' productive efficiency level. In contrast, knowledge spillovers in the high-tech industries are slow but there are continuous productivity benefits from multinational firms.

This study puts a step forward in understanding the mechanism of the spillovers from multinational firms and provides new insight by breaking down industries into high-tech and low-tech groups according to the average complexity of the intermediate goods. Also, this study embraces the mixed evidence for spillover effects shown in the previous literature: an economy with a large share of low-tech multinational firms and low technology transfer cost would experience small or even negative spillovers, one with a large share of low-tech multinational firms but high technology transfer cost would be related to considerable knowledge spillovers, and one with a large share of high-tech foreign firms and low technology transfer cost would be associated with positive or insignificant spillovers. Therefore, the impacts of the multinational firms on the host country firms' productivities cannot be generalized as positive or negative, and they depend on industrial structure of foreign firms and technology transfer cost.

My study raises several issues for further research. First, one important question is whether my results extend to other countries, in particular, developing countries. The availability of the data on intra-firm imports for developing countries would provide more plentiful evidences for my model. Second, I assume a constant trade cost in the model, but it actually varies in trade policies or remoteness of a country. Relaxing the assumption would give more insights in understanding complex knowledge spillovers. Lastly, although the data shows negative impacts of multinational firms on the host country in the low-tech industries, my model does not explain it. It may be due to that market competition or other negative factors dominate positive effects. The identification of those factors and their inclusion in the model would more strongly support the empirical results. More research needs to be done to better understand the complex multinational firms' knowledge spillovers by considering firm, industry, and country dimensions.

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