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Vertical Multinationals, Industry Characteristics, and Endogenous Technology Spillover*

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Abstract

In this paper, we build a model of vertical multinational firms with endogenous spillover that explains recent empirical questions; why developing countries have little technology transfer from foreign direct investment (FDI) and why only low-tech sectors benefit from technology spillover. To explain these questions, we emphasize industry characteristics as well as country characteristics in a small open general equilibrium framework. The model has two main results: First, vertical multinationals and local firms behave differently across industries depending on the level of skilled labor abundance. Second, the degree of competition between multinational and local firms explain the degree of benefits from FDI and why only low-tech sectors have spillover effects in developing countries.

Keywords: Vertical multinational firms, Industry characteristics, Technology spillover, Skilled and unskilled labor, Economic development

JEL Classification: F12, F14, F23, O12, O33

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1 Introduction

For developing countries, superior knowledge of production is an especially important source of economic development. Since the 1960s, the contents of technological change or spillover has been left as an unexplained residual, although many economists recognized the importance of technological diffusion for economic development.[1] During the same period in which theoretical contributions to technology spillover have been developed, some empirical studies were conducted within the framework of international trade.[2]

In the 1990s the study of technology spillover split along two newly emerging paths. One is a series of micro empirical studies, usually using firm level data, while the other path is interested in empirical tests of the endogenous growth model in Macroeconomics. A series of endogenous growth models, such as Barro and Sala-i-Martin (1995) and Grossman and Helpman (1991), enable us to discuss differences in economic growth rates. Barro and Sala-i-Martin (1995) highlighted human capital as a source of the technology differences across countries. Grossman and Helpman's (1991) model clarified the role of dynamic scale economies and the learning mechanism in the catching-up process.

These two paths provide both macro and micro incentives for empirical studies on technological diffusion across countries or across industries. Empirical studies on international technology spillover can roughly be classified into two groups: those that emphasize the trade channel[3] and those that emphasize the foreign direct investment

[1]For the early theoretical example, see Nelson and Phelps (1966) and Findlay (1978).

[2]Several early empirical studies on technology diffusion through foreign direct investment (FDI) include Caves (1974), Globerman (1979), and Blomström and Persson (1983). All these studies conclude that FDI has a positive impact of technology transfer on host countries, i.e., Australia (Caves), Canada (Globerman), and Mexico (Blomström and Persson).

[3]Coe and Helpman (1995) analyze the trade among OECD countries and find positive spillovers and Coe, Helpman, and Hoffmaister (1997) find the positive spillovers between developed and developing countries. On the other hand Keller (1998) cast doubt on these positive spillovers. See Keller (2002)

(FDI) channel. Studies on FDI channel may be further divided into two groups: those that use cross-country estimation and those that employ firm-level estimation.[4] Recent literature concerning crosscountry effects of FDI have some novel findings that FDI contributes technology transfer and hence economic growth. The novelty of this is that the result is only true for some host countries. This insight leads us to the idea of a "threshold of development." That is, in order to benefit from FDI, a host country needs to reach a minimum human capital threshold level. On the other hand, the results of firm level estimations are mixed. Despite these results we are able to gain some valuable insights from this literature, as we will review below.

Cross-Country Evidence

Endogenous growth models and dynamic open trade models also spurred empirical studies on international technology spillovers. The FDI channel of technology spillover on cross-country evidence can be divided further into two groups of studies according to the type of equations estimated. If the growth rate of the economy is regressed on the FDI, we call it "indirect estimation." From the theoretical foundations mentioned above, we know FDI inflow affects the productivity of a host country, and then the productivity change affects economic growth. In other words, the impact of FDI captured in such estimation is indirect.

The first group includes Blomström, Lipsey, and Zejan (1992) and Borensztein, Gregorio, and Lee (1998). These two papers have a strong theoretical foundation in human capital endogenous growth models, in which countries with greater initial stocks of human capital experience more rapid rates of introduction of new goods and thereby tend to grow faster (Lucas 1988 and Romer 1990). These studies use the so

for the detailed survey on trade channel. However, recent literature has focused on the mixed effects of trade and FDI on economic growth. See Lichetenberg and van Pottelberghe de la Potterie (1998) and Baldwin et al., (1999), for references.

[4] One may add the third group that uses case studies.

called "Barro equation," which refers to regressing the growth rate on variables such as initial income level, education level (both primary and secondary), the number of revolutions and coups, the number of assassinations, price fluctuations, and socialist regimes and regional dummies,and so forth.

Blomström et al. (1992) found that FDI has a positive and statistically significant impact on the growth rate in the higher income sample, but not in lower income sample. Since their primary purpose is, however, to investigate conditional convergence, they do not further investigate this phenomenon. Borensztein, Gregorio, and Lee (1998) focus more directly on FDI and economic growth. They concentrate on the estimation of the impact of FDI on economic growth based on the endogenous growth theoretical background.

They found that there must be a threshold level of development according to the human capital accumulation in host developing countries. Thus, FDI contributes to economic growth only when sufficient capability of the advanced technologies is available in the host economy.

In contrast to the indirect estimation of the FDI channel, direct estimation of this channel has the following features: 1. The models are closely related to endogenous growth models, but are relatively free of the specification from the Barro equation. 2. Direct estimation enables us to see the impact of FDI on productivity change in the host country. This is the reason we call this direct.

Xu (2000) investigates the impact of FDI on the host country's productivity by using panel data, which consist of 20 developed and 20 developing countries. Xu's (2000) results clearly show a threshold of human capital level at which FDI benefits productivity. In the developed country sample, the technology transfer effect is positive and statistically significant, but in developing country sample, it is positive but is not significant.

Firm level Evidence

Firm level evidences may roughly be divided into two categories. The first group consists of developed country samples which finds that multinational enterprize (MNE) subsidiaries [5] have positive impacts on the host economy's productivity. This group includes Haskel, et al., (2002) and Veugelers and Cassiman (2003).[6] The second group consists of developing country's samples which has mixed results. This includes Kokko (1994), Haddad and Harrison (1993), Aitken and Harrison (1999), Blomström and Sjöholm (1999), and Blomström et al. (2000).

While the studies with developed country data find the positive spillover effects of FDI, most of the studies analyzing developing countries have failed to find the evidence of positive spillovers. Haddad and Harrison (1993) employ firm-level data of Moroccan manufacturing sector, but they reject the hypothesis that FDI accelerated productivity growth in domestic firms during the second half of the 1980s. However they find that spillover effects are significant for relatively simple technology using sectors and there are no significant transfers of modern technologies. Analyzing Mexican manufacturing industry data Kokko (1994) concludes that the industries where large productivity gaps and large foreign shares occur may explain why spillovers do not exist. Kokko also argues that when foreign affiliates and local firms are in more direct competition with each other, spillover effects are more likely to occur. Aitken and Harrison (1999) find with Venezuelan plant level data that increases in foreign equity participation are correlated with increases in productivity for small plants. However they fail to find the positive spillover effects to other domestic plants. They emphasize the possibility that spillover effects vary across industries. Blomström and Sjöholm (1999) show

[5] Focussing on the argument of vertical multinationals and technology spillover via subsidiaries, we exclude licensing as one of possible supply modes in this paper. Thus, we use the word "multinational firm" and "FDI" interchangeable.

[6] Haskel et al.(2002) analyze UK and Veugelers and Cassiman (2003) use Belgium firm level data, respectively.

with Indonesian detailed establishments data that foreign establishments benefit from spillovers. However, breaking down the industry level they find that spilovers are found in only *food, textiles, wood, chemicals,* and *nonmetal products*[7] industries which are relatively low-tech industries.[8]

Blomström et al. (2000) investigate using Mexican firm level data and conclude that the spillover effect is positive and highly statistically significant in relatively labor intensive industries, but not significant in relatively capital intensive industries.

Cross-country studies identify that the FDI channel exists but for the countries which satisfied a certain human capital requirement, and not for other countries. On the other hand, three points should be noted about firm level evidences. First most of them refer to the possibility or show with clear evidences that spillovers may differ across industries. Second, most of them refer to the host country's absorption capability for technology spillovers as a possible reason for no or little evidences of positive spillovers. Lastly, some evidences show that spilloveres are found only in low-tech industries.

Vertical vs. Horizontal MNE

Empirical studies, however, do not explain the different roles of horizontal and vertical multinational firms mainly because of data availability.[9] Horizontal multinational firms have their headquarters in their home country and final assembly plant in both the host and the home countries. On the other hand, vertical multinational firms split their production process into more than two locations. Keeping their headquarters in their home country, vertical multinational firms assemble final products in the host country.

[7] Blomström and Sjöholm (1999), p920, footnote 7

[8] *Chemicals* range widely from fireworks, plastic tubes, pipes, hoses which are relatively unskilled labor intensive goods, to medicaments, perfume which are relatively skilled labor intensive goods. Blomström et al. show that the capital labor ratios of these chemical products are less than the average of total manufacturing in Mexican case, see Table 9.2, p.139.

[9] See Markusen (1995, 2002) for differences between two types of multinationals. Markusen and Maskus (2001) provide a careful argument on this issue both in theoretical and empirical aspects.

For horizontal multinational firms, the trade-off between exporting and producing in the host economy usually arises. On the other hand, vertical multinationals involve trade-off between cost of producing whole process in source country and cost of breaking up the vertical production structure.

The effects of horizontal and vertical multinational firms can be different in many aspects. First, horizontal multinationals are likely to be substituted for international trade while vertical multinationals are complement to trade. Second, horizontal multinationals are likely to occur between countries of similar development levels while vertical multinationals are more likely between countries with different levels of development. Third, horizontal multinationals generally have more job creation effects on host economy than vertical multinationals.

Figure 1 shows some aspects of differences between horizontal and vertical multinationals which is modified version of Figure 3 in Carr et al. (2003). Volume of subsidiary sales or the number of multinational firms for vertical MNE is declining as countries factor endowment structures or levels of development become similar. On the other hand, the number of horizontal multinationals are an increasing function of similarity between countries. Figure 1 gives simple insights when we consider the effects of MNE on host economy, i.e., we need to distinguish two types of multinationals to identify their effects on the host economy. It means that when we consider the effects of multinationals on host developing economies, we should emphasize vertical multinationals rather than horizontal ones. Although horizontal multinational firms are more important in world capital flows, vertical multinationals are still very important for developing countries especially for their development strategy.

The purpose of this paper is, therefore, to build a theoretical model of *vertical* multinationals that explains empirical findings we discussed previously; why less developed countries have little or no spillover effects from FDI, why spillover effects occur only low-tech sectors, and how MNE behaviors or spillover effects are different across industries. Regarding the last question, it is rather surprising that little theoretical attention has been paid to the industry characteristic of FDI. To explain these questions, we endogenize spillover effects and incorporate industry characteristics into the model.

The rest of this paper is organized as follows. Section 2 presents the model of vertical multinational firm and derive the main implications of the model. Section 3 extends the model to endogenous technology spillover model which is the central aim of this paper. Section 4 refers to implications for economic development of host economy. Section 5 concludes the paper.

2 A Model of Vertical Multinationals

Although the importance of technology spillovers from developed to developing countries have been recognized empirically, few theories try to uncover the mechanism of spillovers.[10]

Recent theoretical contributions focus on the equilibrium conditions in which technology spilloves occur. Markusen and Ethier (1996) analyze multinational firms and technology spillover in a product cycle setting. Their main concern is to investigate the decision making of supply modes (exports, licensing contracts, or multinationals), and endogenous determination of wage rate and the number of multinational firms. They assume that licensing contract and multinational subsidiaries are main routes of technology transfer via labor turnover but exporting is not.

Fosfuri et al.(2001) and Glass and Saggi (2002) focus on narrower point of spillover mechanism. Fosfuri et al.(2001) identify the conditions under which technology spillovers

[10]See Wang and Blomstöm (1992) for survey on the earlier works on this issue. Many of earlier models focus on capital inflow and learning by doing process in dynamic setting

occur using two stage multinational firm's decision game, based on the idea that technology spillovers occur through workers mobility. Trained workers in the multinational's subsidiaries establish local rivals firms. Their other concern is to identify why multinationals provide workers higher wages than local firms do and conditions under which this is true. Glass and Saggi (2002) construct two-country one-shot Cournot game but they concentrate on more host government's policy concern.

The model of this paper is different from both the earlier and recent models in many aspects. Since our model is constructed to explain the empirical findings mentioned in the previous section, we do not focus much on the conditions in which technology spillovers occur. Instead we focus more on the idea that the effects of multinational firms vary across industries and the endogenous determination of technology spillover effcts. The framework of our model is more similar to Markusen and Venables (2000) which construct the horizontal multinational firm model with the varieties of final goods in two country general equilibrium, and Zhang and Markusen (1999) where they make the vertical multinational model under the oligopoly in two country general equilibrium. However, these models study neither industry characteristics nor technology spillovers.

Model

The (host) economy is assumed to be a developing and small open economy with two final goods sectors, X and Y, and two factor inputs of productions, skilled and unskilled labor. While Y-sector is characterized as a perfect competition, X-sector is monopolistic competitive market. While Y-sector produces final good Y using both skilled and unskilled labor X-sector produces final good X with two types of machines; one is low-tech and the other is high-tech machines. Since the host country is less developed, we assume this country is relatively abundant in unskilled labor. We further assume that low-tech machines are produced by only unskilled labor and the high-tech machines are produced by only skilled labor. Under this assumption, the host country has a comparative advantage in the production of low-tech machines. Hence multinational firms have incentives to split the production process of good X in which multinational firms produce and bring high-tech machines to the host country and assemble them with low-tech machines produced in the host country. Factors are perfectly mobile within each country but are immobile between countries. However, high-tech machines are tradable with some transfer and adjustment costs.

The distinct feature of our analysis is to allow the model to focus on the effects of the multinational firms on the host economy under the various industry characteristics as well as country characteristics. While the ratio of fixed endowments of skilled to total labor force stands for the country characteristics, the intensiveness of high-tech machines used in the sector determines the industry characteristics.

Preference

There are two final goods, X and Y, and the preference takes the following Cob-Douglas utility form.

$$u = X^{\gamma} Y^{1-\gamma}, \quad X = \left[n X_d^{\frac{\epsilon-1}{\epsilon}} + m X_m^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}, \quad \epsilon > 1,$$

where γ is the expenditure share to the good X $(0 < \gamma < 1)$, X_d (X_m) is the differentiated good by local (multinational) firms. ϵ is the elasticity of substitution between X_d and X_m. n (m) is the numbers of domestic (multinational) firms. Economy endows fixed amount of skilled and unskilled labor.[11]

Final Goods Sector

There are two final goods sectors; Y is produced using skilled and unskilled labor showing constant returns to scale technology, and Y is assumed numeraire. Good X is produced by two types of producers; domestic producers and multinational firms.

[11]To save the notations, X and Y denote both demand and supply of final goods.

X_d represents each variety produced by domestic producers and X_m is each variety produced by multinationals. Final good Y represents the rest of the economy and is tradable at the fixed world market price. We further assume the trade in good Y is costless. Demands for each final good is as follows;

$$X = \frac{\gamma E}{Q_X}, \quad Y = (1-\gamma)E. \tag{1}$$

where E is total expenditure of the economy which will be defined shortly and Q_X is a composite price index of X which consists of prices of X_d and X_m[12]

$$Q_X = \left[np_d^{1-\epsilon} + mp_m^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}, \tag{2}$$

where p_d and p_m represent the prices of domestic and foreign goods respectively.

Given X, domestic firms and multinationals generate the demand for each variety, X_d and X_m

$$X_d = p_d^{-\epsilon} Q_X^{\epsilon} X, \tag{3}$$

$$X_m = p_m^{-\epsilon} Q_X^{\epsilon} X, \tag{4}$$

Each variety X_d and X_m is produced under monopolistically competitive markets with the following production techniques;

$$X_d = \Psi \min\left\{\frac{Z_L^d}{1-\mu}, \frac{Z_H^d}{\mu}\right\},$$

$$X_m = \min\left\{\frac{Z_L^m}{1-\mu}, \frac{Z_H^m}{\mu}\right\},$$

where Z_i^j, $i = L, H$ and $j = d, m$ is quantity of intermediate goods (machines) used in each final good production. Final good X_d and X_m are produced with two kinds of machines, low tech- and high-tech machines. Machines are assumed to be tradable.

[12] The derivations of Q_X and demand functions for X_d and X_m are already well-stylized. See Markusen (2002), chapter 6, for details.

We further assume that multinationals bring (import) Z_H^m from their home country to this host economy and assemble the final goods X_m using low-tech machines which are produced in the host country. μ indicates the fixed productivity parameter and also indicates the type of industry assumed to lie between 0 and unity. Ψ is productivity parameter and captures spillover effects from multinational firms in which the activity of multinationals has an externality to local firm production. This productivity parameter contains the quantity of skilled labor who obtain knowledge of new technology and absorptive capability of host economy that will be discussed in next section. In this section Ψ is assumed to be unity, that is, there are no spillover effects.

Technology of Y-sector is assumed Cob-Douglas and produced with skilled and unskilled labor;

$$Y = AL_Y^{\beta} H_Y^{1-\beta},$$

where A is productivity parameter, L_Y and H_Y denote unskilled and skilled labor employed in Y-sector.

Cost Functions and prices

Since final good Y is numeraire and produced under perfectly competitive market, we have following unit cost function of Y-sector;

$$c_Y(w_L, w_H) = w_L^{\beta} w_H^{1-\beta} = 1 \tag{5}$$

with the normalization $A = \beta^{-\beta}(1-\beta)^{\beta}$.

Varieties of goods X are produced with an increasing returns to scale technology. Thus domestic and multinational firms face the following cost functions;

$$\Gamma_d = \Psi^{-1}[(1-\mu)q_L + \mu\, q_H](X_d + F_d), \tag{6}$$

$$\Gamma_m = [(1-\mu)q_L + \mu(\, t_z q_H^* + \phi)](X_m + F_m), \tag{7}$$

where q_i, $i = L, H$ is the price of intermediate machine Z_i^j and q_H^* is the price of machine that multinational firms bring from their home country. t_z is the transportation cost which is greater than 1. ϕ is an adjustment cost that is necessary to install the new machines into the host economy's production. F_d and F_m are fixed costs for each type of firm and we assume that $F_m < F_d$, that is, multinationals have some firm level advantage to establish new plants, such as marketing know-how, distribution network, management strategies and so forth. These cost functions say that the industry with lower μ is characterized as a low-tech machine intensive industry, and with higher μ is a relatively high-tech machine intensive industry.

Since X_d and X_m are produced in the monopolistic competitive market, their each price becomes

$$p_d = \frac{\epsilon}{\epsilon - 1} c_d, \quad (8)$$

$$p_m = \frac{\epsilon}{\epsilon - 1} c_m, \quad (9)$$

where c_d and c_m are marginal costs of domestic and multinational firms, respectively.

We next define the firm's profit functions for domestic and multinational firms;

$$\pi_d = p_d X_d - c_d(X_d + F_d)$$

$$\pi_m = p_m X_m - c_m(X_m + F_m)$$

Each type of intermediate machines is produced with one unit of each type of labor, that is, low-tech machine Z_L^j is produced with one unit of unskilled labor and high-tech machine Z_H^j is produced with one unit of skilled labor. Intermediate good sectors are assumed perfectly competitive so that $q_i = w_i$, $i = L, H$.[13]

Making use of equation (5) and defining $w = w_H/w_L$, we can rewrite w_L and w_H as

$$w_L = w^{\beta-1}, \quad w_H = w^{\beta},$$

[13]Since intermediate machines are tradable across borders but workers do not, this assumption is needed.

We assume that to adjust a high-tech machine brought by the multinational firm to the low-tech machine which is produced by the local firm, the subsidiary needs a help of local skilled labor. In other words, adjustment cost ϕ is a function of skilled labor's wage rate. Using the transformation of wage rates above, unit cost functions become

$$c_d(w) = \Psi^{-1}\left[(1-\mu)w^{\beta-1} + \mu\, w^{\beta}\right], \tag{10}$$

$$c_m(w) = (1-\mu)w^{\beta-1} + \mu\,(t_z w^{*\beta} + \alpha w^{\beta}), \tag{11}$$

where w^* is the wage ratio of skilled to unskilled labor in multinational's home country and α is units of skilled labor required to adjust new machine to host country's low-tech machine assuming $0 < \alpha < 1$.[14]

Since we assume full employment and fixed labor supply, the total factor income, E, of this economy is $w_L L + w_H H$. Using the previous transformation of w, total factor income equation is rewritten as;

$$E(w) = w^{\beta-1}L + w^{\beta}H \tag{12}$$

Equilibrium Conditions

Two more equilibrium conditions are needed for closing the model, factor market equilibrium and zero profit conditions. Labor markets are assumed perfectly competitive with fixed labor supplies so the equilibrium conditions are described as $L = \beta\, Y w^{1-\beta} + L_X$ and $H = (1-\beta)Y w^{-\beta} + H_X$. L_X and H_X are unskilled and skilled labor required for X-industry. From these equations, the function of relative wage is expressed as a function of L_X and H_X,[15]

$$w = \frac{1-\beta}{\beta}\,\frac{L-L_X}{H-H_X}. \tag{13}$$

[14]To produce one unit of X_m, less than one skilled labor is needed. This means that skilled labor works a part of the day not a full day.

[15]First, eliminating Y from equations for L and H, and solving the result for w, we have equation (13).

Unskilled and skilled labor in X-sector consist of local and multinational firms' employees,

$$L_X = n(1-\mu)(X_d + F_d) + m(1-\mu)(X_m + F_m), \quad (14)$$

$$H_X = n\mu(X_d + F_d) + \alpha m\mu(X_m + F_m). \quad (15)$$

The first term of right hand ides of equations (14) and (15) represent unskilled and skilled labor employed by local firms. The second term of right hand sides of equations (14) and (15) represent unskilled and skilled labor employed by multinational firms.

Finally zero profit condition for each firm is directly derived from each profit function setting equal zero,

$$X_d = (\epsilon - 1)F_d \quad (16)$$

$$X_m = (\epsilon - 1)F_m \quad (17)$$

Combining these zero profit conditions together with factor market equilibrium conditions, w can be described as a function of n and m that has the following properties;

$$\frac{\partial w(n,m:\mu)}{\partial L} > 0, \quad \frac{\partial w(n,m:\mu)}{\partial H} < 0$$

$$\frac{\partial w(n,m:\mu)}{\partial n} \gtrless 0 \quad \Leftrightarrow \quad \mu \gtrless \frac{H - H_X}{L - L_X + H - H_X},$$

$$\frac{\partial w(n,m:\mu)}{\partial m} \gtrless 0 \quad \Leftrightarrow \quad \mu \gtrless \frac{H - H_X}{\alpha(L - L_X) + H - H_X}.$$

These properties say that an increase in (absolute term of) $L(H)$ raises (lowers) the relative wage of skilled to unskilled labor w. In other words, the $L(H)$ abundant country tends to have higher (lower) wage ratio w. This captures the country characteristic. On the other hand, parameter μ denotes the industry characteristic.

The system of equations consists of 15 equations, such as (1)(two equations), (2), (3), (4), (8), (9), (10), (11), (12), (13), (14), (15), (16), and (17). These 15 equations solve 15 unknown variables, such as $\{X, Y, X_d, X_m, p_d, p_m, c_d, c_m, Q_X, w, E, L_X, H_X, n, m\}$. (see Appendix 3 for more detail.).

Intuitive Arguments

To identify the impact of multinationals, let us first consider the situation when there were no multinationals. Therefore equilibrium conditions are described by equations (3) and (13). Figure 2 shows the relationship between w and μ. Derivations of curves are explained in Appendix A. The equilibrium conditions for w and n are divided into two cases depending on the relative size between μ and the share of skilled labor in total labor force, $h = H/(L+H)$. As Figure 2 shows that the determination process of equilibrium w and n are different across sectors. The upper panel of Figure 2 which is the case for $\mu < h$ have relatively larger number of domestic firms and lower wage rate than the lower panel of Figure 2 which is the case for $\mu > h$. In the upper panel, both equations, (3) and (13) have maximum attainable numbers of domestic firms which are expressed by the limiting values of $H/(\epsilon F_d \mu)$, and $\gamma H/(\epsilon F_d \mu)$, respectively. In the lower panel while equation (13) has the same maximum number of domestic firms, equation (3) has the minimum limit number of domestic firms which is expressed by $\gamma H/(\epsilon F_d \mu)$.

It is clear that the wage ratio in low-tech sector (upper panel) is lower than that of high-tech sector (lower panel). Figure 2 also shows that the number of local firms in low-tech sector is greater than that in high-tech sector. Absolute number of local firms, on the other hand, depends on coutry characteristics, h.

Entry of multinationals affects equilibrium in both panels though changes in limiting values. An increase in the number of multinational firms shifts the limit lines leftward because the number of multinational firms enters in the denominator of the limiting values. As a result, curves of equations (3) and (13) also shift leftward. It is obvious that the entry of multinational firms reduces the number of local firms. It is, however, not obvious whether it reduces or raises the wage ratio.

To see whether the wage ratio increases or decreases, we should solve the general equilibrium model that consists of three equations, (3), (4) and (13) simultaneously. Since it is very difficult to solve the whole system analytically, we solve it numerically instead in the next subsection.

General Equilibrium

To show the characteristics of industry as well as country characterisics, we draw the graphs over μ for various skilled labor endowment ratios. Figure 3 shows the numbers of domestic and multinational firms without spillovers, i.e., $\Psi = 1$ over μ for three different cases of $h = H/(H+L)$: upper figure has $h = 0.20$, middle figure has $h = 0.25$, and lower figure has $h = 0.30$.

Upper panel ($h = 0.20$) says that the entry of multinationals drives local firms away from many high-tech industries. While the domestic firms prevail only relatively low-tech industries (low μ) multinational firms have large market shares in relatively high-tech sectors (high μ). This explains the case of least developed countries where multinational firms with relatively high technology overcome the local firms because of the large technology gap. Local and multinational firms compete each other only in low-tech sectors.

Middle panel ($h = 0.25$) shows the case where local firms are active for all sectors even after the entry of multinationals while multinational firms emerge in relatively high-tech sectors (higher μ). Multinational firms gain larger market shares in higher technology sectors. Local and multinational firms compete in a wide range of industries.

Lower panel shows the case of $h = 0.30$ which is still a developing but not severely scarce in skilled labor. In this case, multinational firms emerge only in high-tech sectors and local firms exist for all sectors although the number of local firms is decreasing with μ. Local and multinational firms compete in only relatively high-tech sectors.

Country characteristics which is indicated by h bring the following insights: the number of multinational firms is declining and the range of sectors shifts toward high-tech sectors as h increases, while the range of local firms expands as h increases. These observations on the country characteristics match the empirical findings about vertical multinational firms that we have discussed in introduction section.

In the next section, introducing technology spillover into these general equilibrium insights of industry and country characteristics, we explain the main question in this paper, i.e., why technology spillovers hardly occur in less developed countries, and only low-tech sectors benefit from FDI.

3 Endogenous Technology Spillover

Technology spillovers pass two stages. The first stage is where subsidiaries of multinational firms bring superior technology and knowledge of production into the host country. At the second stage mainly local skilled workers employed by subsidiaries learn new technology and then new technology disperses to local firms via labor turnover.[16] In addition to these factors, the degree of technology spillover also depends on the absorption capability of the host industry as many empirical studies indicate.

Thus the degree of technology spillover depends on the number of skilled labor employed by the multinationals, the frequency of labor turnover, and absorption capability of the industry. To make the story simple, we assume that the absorption capability of each industry is the share of number of local firms in the total number of firms in the industry. Blomström and Kokko (1998) state that spillovers from competition are not determined by foreign presence alone, but rather by the simultaneous

[16] See, for example, Hall and Khan (2003) for the importance of skilled workes on the technology spillovers. See also Fosfuri et al.(2001). Other than labor turnover, spillovers may arise through demonstration effects and backward and forward production linkage effects.

interaction between foreign and local firms. They also point out that large foreign presence may even be a sign of a weak local industry, where local firms have not been able to absorb any productivity spillovers, while a high level of local competence contributes to raise the absorptive capacity of the host country. Blomström et al. (2000) also state that spillovers appear in industries with moderate technology gaps between local and multinational firms, but not in industries with large technology gaps. We assume that labor turnover potentially occurs for every skilled worker employed by multinational firms. In this sense, we may refer to our measure as *potential* degree of spillover.

Hence the (potential) degree of technology spillover is defined as follows;

Share of Skilled Labor for MNE to Total Labor × Industry's Absorption Capability.

In our notation,

$$\frac{H^{MNE}}{L+H} \times \left(\frac{n}{m+n}\right).$$

If there were no multinational in the host country, in other words, no skilled labor in multinational subsidiaries ($H^{MNE} = 0$), technology spillover never occurs. The other extreme case arises when there were no local firms ($n = 0$). In this case no spillover occurs because there are no receivers of new knowledge of high-tech machines. If there were many local firms and a small number of multinational subsidiaries, local firms compete one another to hire skilled workers who have learned new knowledge from the multinational subsidiaries and compete to provide a better offer to them. In this case, new technology is likely to be transferred to local firms with higher probability ($n/(n+m)$). We can interpret this to mean that there exists a small technology gap between local and foreign firms. On the other hand, if there were a few local firms and many multinational subsidiaries, skilled workers who have been working for the multinational subsidiaries have more choices to move to. In this case, technology spillover from multinationals to local firms is less likely to occur, because they are likely to move to other multinationals with higher probability $(1-n/(n+m)=m/(n+m))$. We can interpret this to mean that there exists a large technology gap between local and multinational firms.

To endogenize spillover effects in our model, Ψ is now defined as follows:

$$\Psi = 1 + \left(\frac{H^{MNE}}{L+H}\right)\left(\frac{n}{n+m}\right).$$

General equilibrium solutions are obtained by exactly same way as described in Appendix 3. However, we have now 16 equations including an equation for Ψ and 16 unknown variables including Ψ.

Figure 5 shows the number of local and multinational firms with and without spillover effects for various skilled labor ratios. All cases of hs show that technology spillover raises the number of local firms and reduces the number of multinational firms for sectors in which local and multinational firms coexist. Important finding from Figure 5 is that spillover occurs in relatively low-tech sectors for the economy with low hs and in relatively high-tech sectors for the economy with high hs. For example, while the economy with $h = 0.20$ has spillover effects in sectors from 0.15 to 0.5, the economy with $h = 0.30$ has effects in sectors over 0.55. Implication of this numerical example is that less developed country has spillover effects only in low-tech sectors while relatively skill abundant developing country has spillover effects in high-tech sectors. However Figure 5 does not tell the degree of spillover effects for different hs. Hence we isolate the effects of spillover next.

Figure 6 shows the effects of technology spillover over industry characteristics, μ. The vertical axis stands for the value of $\Psi - 1$ defined above. It is directly observed from Figure 6 that the locus of technology spillover becomes radically smaller as h decreases. This means that the less skilled labor ratio the less benefit from technology spillover. For example, the country with $h = 0.20$ potentially benefit from FDI much less than the country with $h = 0.25$ does. This prediction explains the empirical evidence that the endowment of skilled labor of a country is crucially important for technology spillovers.

Figure 6 also indicates that the host country with lower h has a potential spillover in only relatively low-tech industries. The economy with $h = 0.20$, for example, has an industry range of spillovers between 0.15 and 0.5 that are low-tech sectors, while the economy with $h = 0.30$ has an industry range over 0.6 that are high-tech industries. This prediction explains another empirical evidence that less developed countries benefit from FDI only in low-tech sectors. This also tells us the importance of the technology gap between local and multinationals for obtaining spillovers. The prediction, that spillovers appear only in sectors in which there is competition between local and multinationals, explains the empirical findings by Kokko (1994) and Blomström et al. (2000), etc.

Figure 7 represents the spillover effects over country characteristics h. The vertical axis stands for weighted sum of potential technology spillove effects of Figure 6 which is roughly equal to the area under the curve for each h in Figure 6. Figure 7 clearly shows that the effects of spillover through *vertical* multinational firms initially increases with h but tempers with higher h and eventually becomes zero. It means that to obtain technology spillover an economy must have some level of skilled labor ratio which explains the threshold hypothesis of technology spillover. As we have seen in Figure 1, since the number of multinational firms approaches zero as h increases, spillover effect from vertical multinational firms also becomes smaller as h increases. It should be noted that our model focusses on vertical multinationals, hence we isolate the *vertical* spillover effects from *horizontal* spillover effects. As many empirical evidences suggest that horizontal spillover may occur in host economies with high skilled labor ratio h. It is, thus, possible that the economy with high h has greater *horizontal* spillover effects.

4 Implications for Economic Development

Our spillover model addresses the importance of skilled labor and a competitive environment between local and multinational firms for technology spillover. This implication suggests a developing host country should educate their workforce. This education reduces the skilled labor scarcity which allows local firms to compete with multinationals. This competition, in turn, enables the spillover effect. In this section we consider the question how the host economy can develop or how it can increase the share of skilled workers which eventually leads to increase the competitiveness of local firms.

Let us assume that to create skilled labor, education is necessary. Individual worker has an incentive to have education to obtain skill if the wage differential between skilled and unskilled labor exceeds education cost, λ,

$$w_H - w_L \geq \lambda.$$

Because we don't consider explicitly the role of the government, the only source of this education cost is operating surplus (short-run profit) of the local firms defined by $(p_d - c_d)X_d$. Local firms may have incentives to provide education to unskilled workers since an increase in the share of skilled workers decrease the relative wage, and thus decrease their production costs. If the operating surplus exceeds the education cost, local firms choose to pay the education costs. Assuming the education cost, λ, equals a portion of the wage differential, $\delta(w_H - w_L)$, $\delta \in (0, 1)$, hence,[17]

$$\left[(1-\mu)w^{\beta-1} + \mu w^{\beta}\right] F_d - \delta(w_H - w_L) \geq 0.$$

Figure 8 shows the loci of operating surplus less education cost for three δs for three hs. In the less-developed country ($h = 0.20$), only very low-tech sectors of local firms

[17] Using equations (8), (10), and the zero-profit condition, Operating surplus, $(p_d - c_d)X_d$, reduces $\left[(1-\mu)w^{\beta-1} + \mu w^{\beta}\right] F_d$.

can afford the education cost when the education cost is high ($\delta = 1.0$, or 0.75).[18] When the education cost is very low ($\delta = 0.5$), all sectors are willing to pay the education cost.

On the other hand, in the economy with $h = 0.30$, local firms can afford relatively higher education cost ($\delta = 0.75$). Even when the education cost is very high ($\delta = 1.0$), lower and higher technology sectors are willing to provide the cost. It simply means that the economy with relatively high skilled labor ratio is more likely to benefit from FDI and eventually more likely to industrialize.

For the country with low h, only FDI promotion policies are not adequate. To benefit from technology spillover, it should raise the skill endowment by providing education to unskilled labor and create competitiveness of local firms. However, economic incentives of local firms and unskilled workers to be educated are not enough for low-h host country. A strong push to raise the skill endowments or reduce the education cost is needed for development.

5 Conclusions

Although recent empirical evidence on multinational firms and technology spillovers suggest the importance of industry characteristics as well as country characteristics, little theoretical attention has been devoted to the industry differences. There are two important issues regarding the empirical evidence of industry differences. First, the impact of FDI varies across countries depending on the level of their human capital endowment. Second, the evidence also suggests that skilled labor scarce countries hardly benefit from FDI inflow and that if they do there are only spillovers in low-tech sectors.

[18] As Figure 2 shows there are no local firm exist in high-tech sectors for $h = 0.20$.

By introducing the industry characteristics, our endogenous technology spillover model of a small open economy with vertical multinationals has identified (1) in a severely skilled labor scarce country, local firms are active only in low-tech sectors while multinational firms emerge in relatively high-tech sectors. In this setting, multinational firms occupy the whole of the high-tech industry market. (2) in a moderately skilled labor scarce developing country, local firms are active in all sectors but tend to be more active in lower technology sectors. Multinational firms enter relatively high-tech industries. In these high-tech sectors, multinational firms get the larger share of the market than local firms but local firms are able to compete with multinational firms for a portion of market share. (3) In a country with relatively large amount of skilled labor, local firms are active in all sectors while multinationals are active only in high-tech industries. Market shares are dominated by local firms for all sectors.

Applying these features of our model to empirical findings, we have the following main result. Combining the industry characteristics of vertical multinationals together with the absorption capability of technology spillovers we explained that in less developed countries foreign multinationals drive out local firms in many high-tech sectors because of the wide gap in technology. This in turn implies that spillover effects from multinationals to local firms are very small. In this case, local firms are too weak to compete with multinational firms in many high-tech sectors. Only in low-tech sectors, can local firms compete with multinationals and thus spillover effects occur only in low-tech sectors. In relatively skilled abundant economies, such as the Asian newly industrializing countries, local firms can survive after investment liberalization and compete with multinationals in all industries. In this case, knowledge of technology is smoothly transferred to local firms.

On designing investment liberalization policy, the clear message of this paper is that different responses in industries, such as the share of local firms, absorption capability, and property rights. etc., should be taken into account as well as development level of the host country. Furthermore, our model predicts that the role of education to acquire skill and creation of competitive markets are especially important for technology spillover.

There are, of course, some important issues that are left out of this modelling strategy. Two possible extensions should be noted for the further research. First, as we have discussed in the introduction, for simplicity we have assumed that there are only vertical multinationals in the economy. However, horizontal multinationals may explain more clearly the threshold hypothesis of spillovers through multinational firms between developed and developing countries. Second, trade cost of intermediate goods do not play an important role in our model because trade-off between vertical FDI and international trade was not a main concern in this paper. However, decision making of trade-FDI option of foreign enterprizes may enrich the implications of the model.

Appendix

A Derivation of Figure 2

To draw the Figure 1, we assume that there are no multinational firms ($m = 0$) in the host economy. Plugging equations (1), (2), (8), (10), and zero profit condition for x_d into equation (3) and rearranging, we have the following function of relative wage w;

$$w = \frac{\gamma L - n\epsilon F_d(1-\mu)}{nF_d\mu - \gamma H}, \tag{18}$$

which describe the relationship between relative wage w and the number of local firm n.

Differentiating equation (18) with respect to n yields the following sign condition:

$$\frac{dw}{dn} \gtreqless 0 \quad \Leftrightarrow \quad \mu \lesseqgtr \frac{H}{H+L}.$$

On the other hand, labor market equilibrium condition (equation (13)) with equations (14) and (15), keeping $m = 0$, yield the following function of w;

$$w = \frac{1-\beta}{\beta}\frac{L - n(1-\mu)\epsilon F_d}{H - n\mu\epsilon F_d}, \tag{19}$$

which also describe the relationship between wage ratio w and the number of local firms n.

Differentiating equation (19) with respect to n gives the following sign condition;

$$\frac{dw}{dn} \gtreqless 0 \quad \Leftrightarrow \quad \mu \gtreqless \frac{H}{H+L}.$$

y-intercepts are derived from setting n equal zero for equations (18) and (19). Limiting values are obtained by equating the denominator to zero in both equations.

B Numerical Example

All simulated figures (from Figure 2 to Figure 7) have the following common numerical values;

α	β	γ	ϵ	F_d	F_m	w^*	t_z
0.5	0.5	0.5	3.0	1.0	0.7	1.2	1.2

Each industry characteristic $h = H/(H+L)$ is used from the following numerical values:

h	0.18	0.20	0.25	0.30
H	18	20	25	30
L	82	80	75	70
$H+L$	100	100	100	100

C General Equilibrium Structure

In Section 2 we assume that there are no spillovers ($\Psi = 1$). The system of general equilibrium consists of following 15 equations:

Demand Block: (1),(3),(4)

$$\begin{aligned} X &= \frac{\gamma E}{Q_X}, \\ Y &= (1-\gamma)E, \\ X_d &= p_d^{-\epsilon} Q_X^{\epsilon} X, \\ X_m &= p_m^{-\epsilon} Q_X^{\epsilon} X. \end{aligned}$$

Prices: (2),(8),(9),(13)

$$\begin{aligned} Q_X &= \left[n p_d^{1-\epsilon} + m p_m^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}, \\ p_d &= \frac{\epsilon}{\epsilon - 1}\, c_d, \\ p_m &= \frac{\epsilon}{\epsilon - 1}\, c_m, \\ w &= \frac{1-\beta}{\beta}\, \frac{L - L_X}{H - H_X}. \end{aligned}$$

Supply Block: (10),(11)

$$\begin{aligned} c_d(w) &= \Psi^{-1} \left[(1-\mu) w^{\beta-1} + \mu\, w^{\beta} \right], \\ c_m(w) &= (1-\mu) w^{\beta-1} + \mu\, (t_z w^{*\beta} + \alpha w^{\beta}). \end{aligned}$$

Factor Income: (12)

$$E(w) = w^{\beta-1}L + w^{\beta}H.$$

Labor Market Equilibrium Conditions: (14),(15)

$$\begin{aligned} L_X &= n(1-\mu)(X_d + F_d) + m(1-\mu)(X_m + F_m), \\ H_X &= n\mu(X_d + F_d) + \alpha m\mu(X_m + F_m). \end{aligned}$$

Zero Profit (Free Entry) Conditions: (16),(17)

$$\begin{aligned} X_d &= (\epsilon - 1)F_d \\ X_m &= (\epsilon - 1)F_m. \end{aligned}$$

These 15 equations solve 15 unknowns, such as X, Y, X_d, X_m, p_d, p_m, c_d, c_m, Q_X, w, E, L_X, H_X, n, and m.

To solve the system, with the function of $w(n, m : \mu)$, we can rewrite c_d and c_m (equations (10), (11)) as functions of n and m. Plugging $c_d(w(n, m : \mu))$ and $c_m(w(n, m : \mu))$ into equations (2), (8) and (9), we have Q_X, p_d and p_m as functions of $w(n, m : \mu)$. Combining these results together with equation (12), we obtain the equation of X, i.e., (1), as a function of $w(n, m : \mu)$. Finally using these results, we can describe the demand functions for X_d and X_m (equations (3) and (4)) as functions of n and m. Two equations, (3) and (4), solve the remaining endogenous variables, n and m

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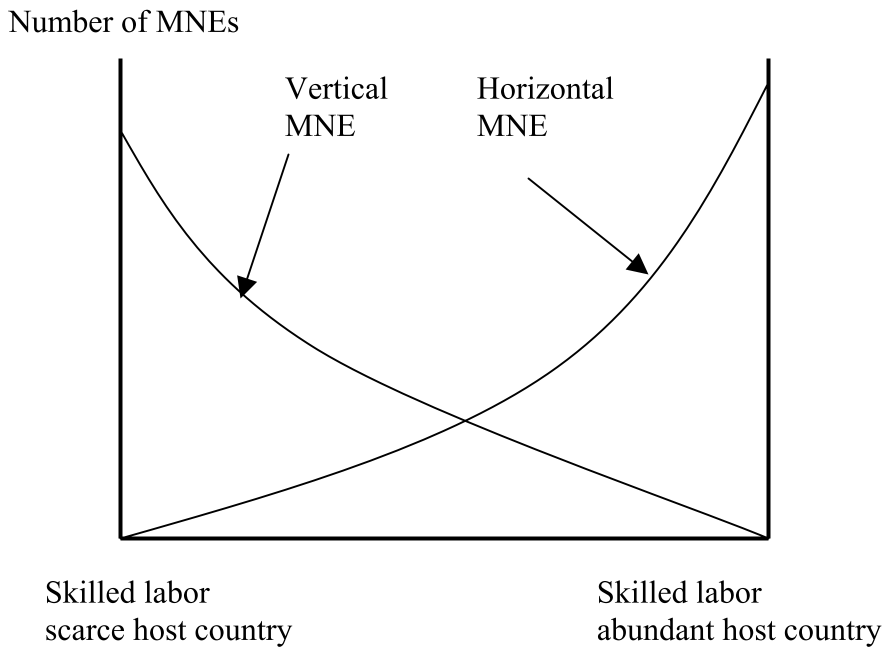


Figure 1
Number of Horizontal and Vertical Multinational Firms
Source: Carr, Markusen, and Maskus (2003), Figure 3.

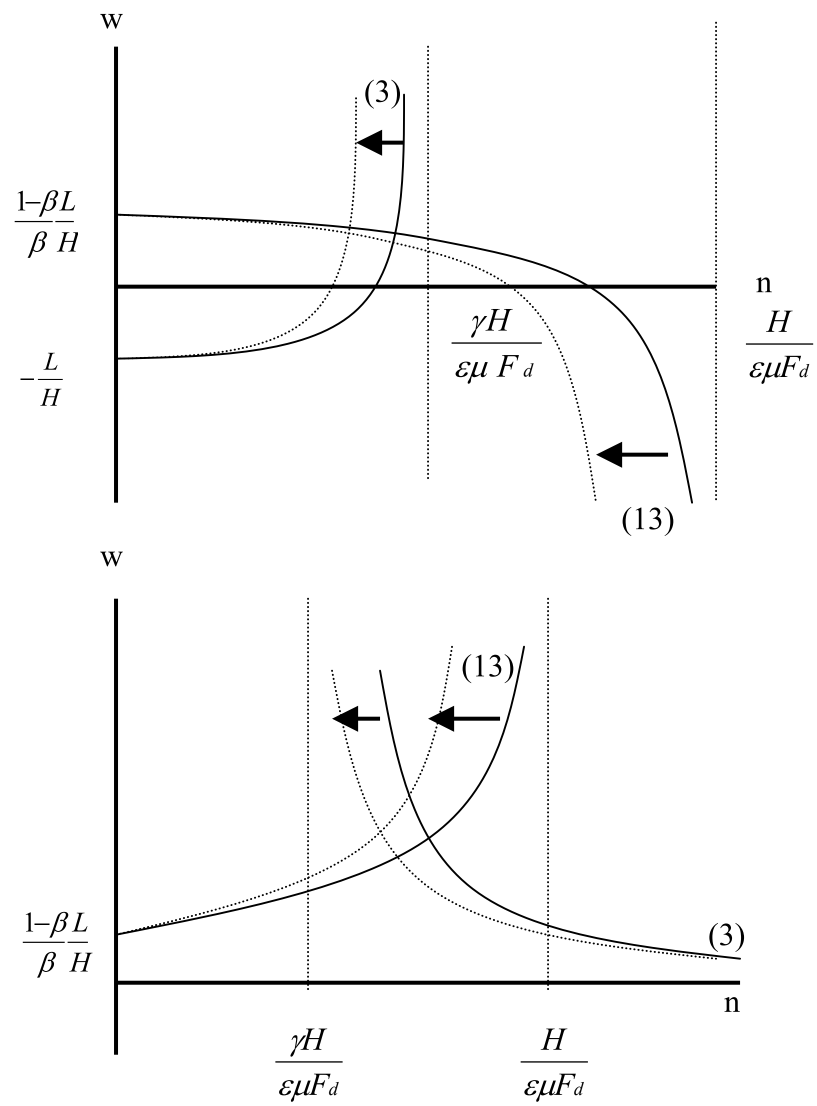
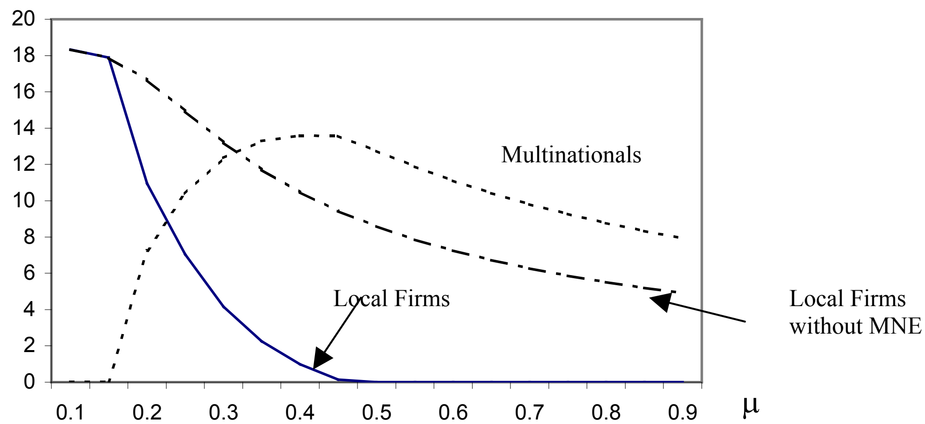
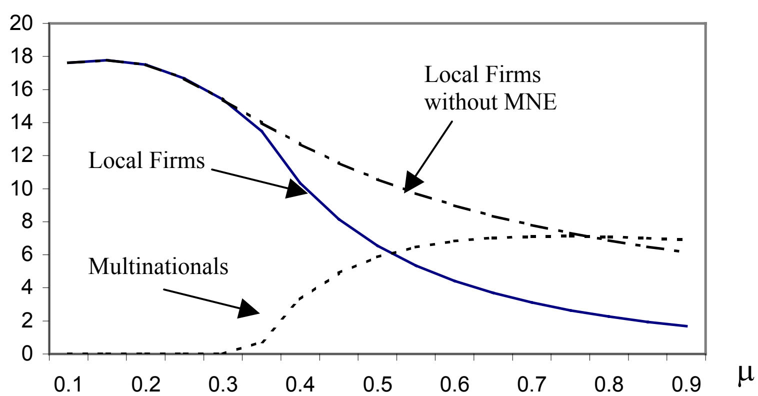


Figure 2
Impact of Multinational Firms
Upper Panel: $\mu < h$
Lower Panel: $\mu > h$
$h = H/(H+L)$

h=0.20



h=0.25



h=0.30

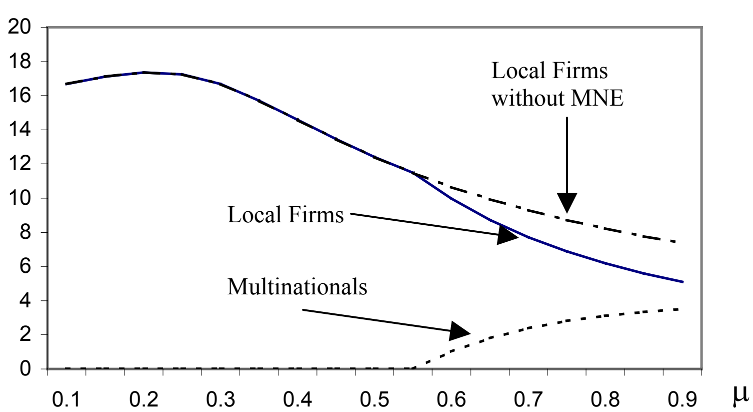


Figure 3
Number of Local and Multinational Firms (without Spillovers)

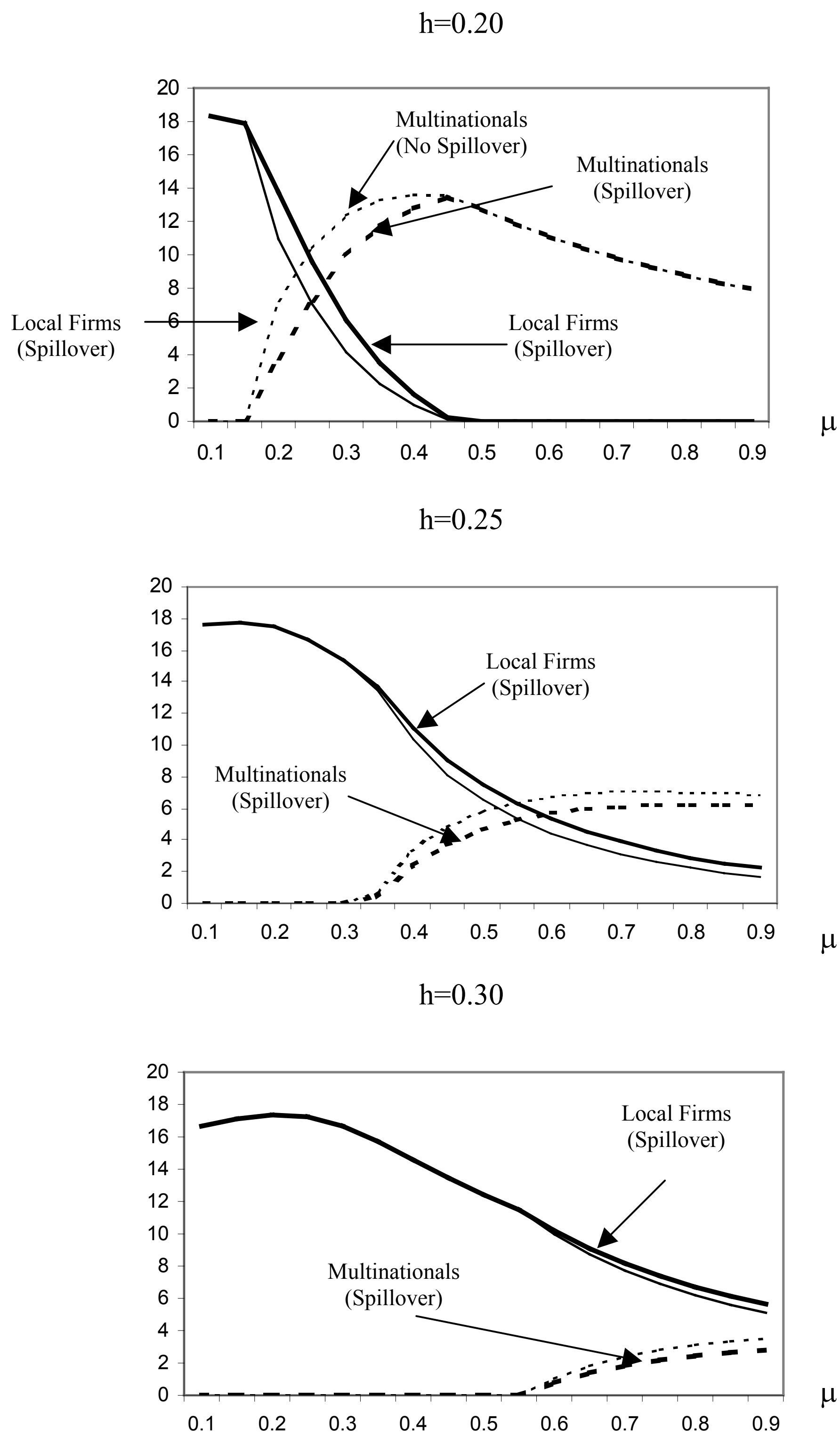


Figure 4
Number of Local and Multinational Firms
(with and without Spillovers)

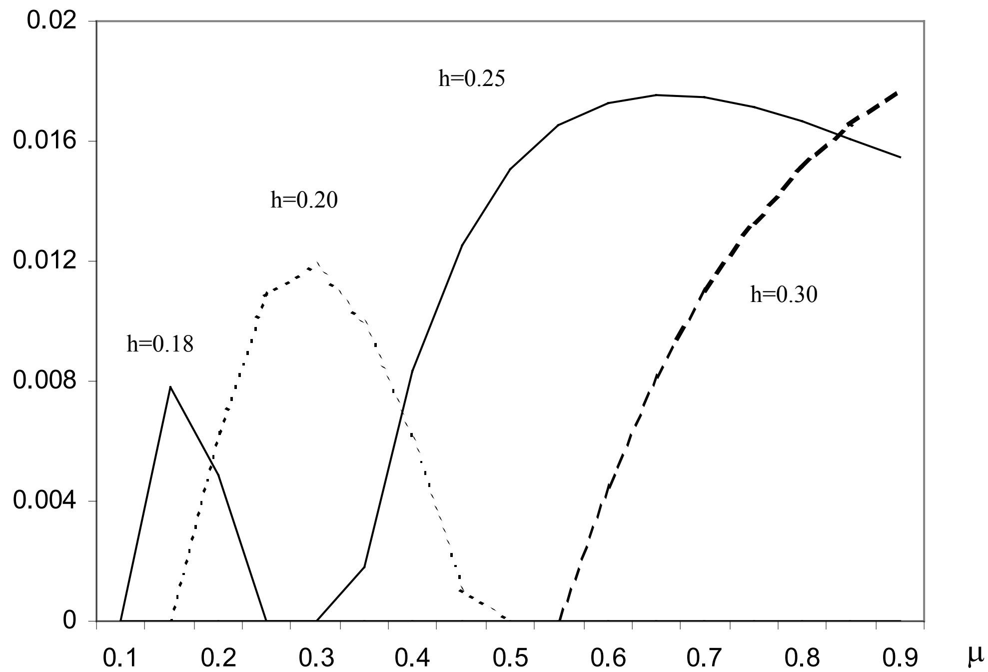


Figure 5
Potential Technology Spillovers

Vertical axis : $\left(\frac{H^{MNE}}{L+H}\right)\left(\frac{n}{n+m}\right)$

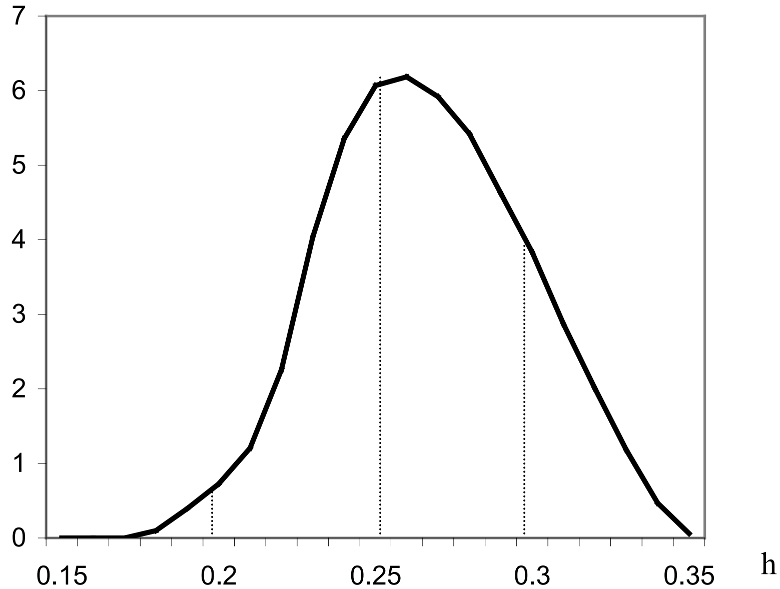
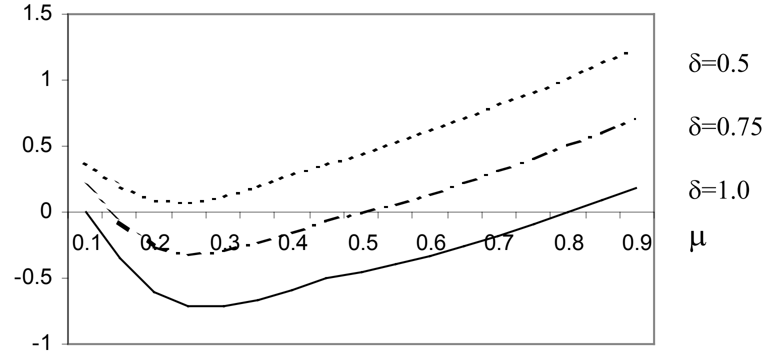


Figure 6
Spillover Effects of Vertical Multinationals
(Country Characteristics)

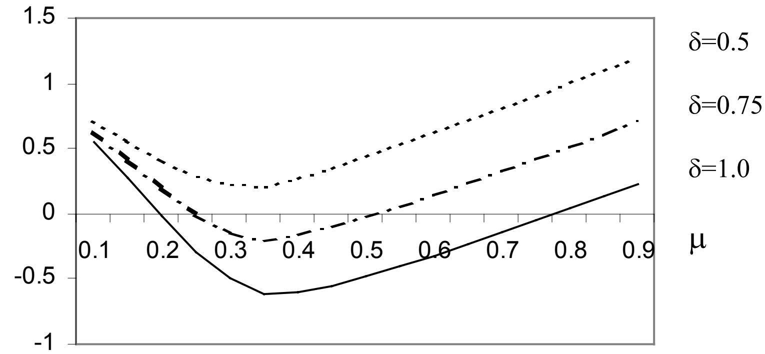
h=H/(H+L)

Vertical axis: $\sum_{\mu=0}^{1}\left(\frac{H^{MNE}}{L+H}\right)\left(\frac{n}{n+m}\right)\mu$

h=0.20



h=0.25



h=0.30

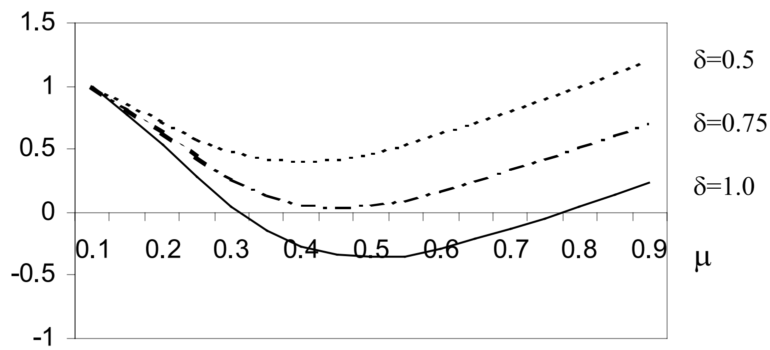


Figure 7
Operating Profit vs. Education Cost (λ)

$$\left[(1-\mu)w^{\beta-1} + \mu w^{\beta}\right]F_d - \lambda, \text{ where } \lambda = \delta(w_H - w_L)$$