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Does horizontal FDI lead to more knowledge spillovers than vertical FDI?

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Does horizontal FDI lead to more knowledge spillovers than vertical FDI?

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Abstract

We develop a simple model that endogenises the difference in spillovers between horizontal and vertical FDI. We find that even though horizontal MNEs may transfer more advanced technology abroad, this does not imply that more knowledge spillovers occur. Despite the higher potential for knowledge spillovers, local firms are less likely to absorb the more advanced technology, while horizontal MNEs may take stronger action to prevent knowledge spillovers from occurring. The technological stance of the host country is thus vital for determining which type of FDI yields the highest knowledge spillovers.

1 Introduction

Foreign direct investment (FDI) attracts warm attention from governments in developed and developing countries. A prime reason for this interest are the benefits FDI allegedly have for host economies. Apart from direct effects on employment and income, governments expect FDI to generate important spillover effects, among them technological or knowledge spillovers effects. From an economic perspective knowledge spillovers are a valid reason for government intervention. The social benefits of FDI will be larger than the private benefits, leading to suboptimal levels of investment. Forming such a classic example of market failure, the academic literature has devoted much attention to establishing knowledge spillovers, finding it hard however to distinguish knowledge spillovers from other sources of benefits from FDI (e.g. Smeets, 2008, Blömstrom and Kokko, 1998; Görg and Greenaway, 2004).

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The basic case for government intervention is the same for developed and developing countries. The extent by which knowledge spillovers occur in either type of country will be different though. The reason is that FDI in developed countries is mainly market seeking, aiming to serve local markets through local sales rather than through exports. By contrast, in developing countries FDI typically aims to make use of the cheap resources those countries offer, in order to establish efficiency gains in the production chain. While the latter is referred to as vertical FDI, the former is known as horizontal FDI. Both types of FDI have in common that the investing firms generally originate from developed countries, though recently the share of developing countries in outward FDI has increased (e.g. UNCTAD, 2008), while also tapping into developed countries' local knowledge bases of developed countries has been mentioned as reason to engage in vertical FDI (Smeets, 2009).

The argument in the literature is that horizontal FDI will yield higher knowledge spillovers than vertical FDI. The reasoning is as follows. If a firm invests abroad to gain market access, its competitive advantage over local firms should be sufficiently high to compensate its 'burden of foreignness', that is: the disadvantage it has regarding knowledge of local markets, consumer preferences and business practices. Accordingly, the firm will transfer part of its knowledge capital to the local subsidiary, giving it a competitive advantage, but also increasing the potential for knowledge spillovers. For vertical FDI this is much less the case. Seeking efficiency gains, vertical FDI only concerns transferring abroad those parts of the firm's value chain leading to efficiency gains. Less knowledge is transferred, implying a lower potential for knowledge spillovers than from horizontal FDI (Beugelsdijk et al., 2008). Moreover, the knowledge transferred will typically be less technologically advanced, decreasing knowledge spillover potential even more (Driffield and Love, 2007).

This would be bad news for developing countries, since they mostly rely on incoming vertical FDI. By contrast, it would make a stronger case for government intervention in developed countries, relying as they do on horizontal FDI. In this paper we challenge the view that horizontal FDI leads to higher spillovers than vertical FDI. To make our point, we develop a simple model that endogenises the difference in spillovers between horizontal and vertical FDI, showing that knowledge spillovers are an intricate outcome of the host country's technological stance, the absorptive capacity of local firms, and strategic behaviour of MNEs. We will show that even though horizontal MNEs may transfer more advanced technology abroad, this does not imply that more knowledge spillovers occur. Despite the higher potential for knowledge spillovers, local firms will also find it harder to absorb the more advanced technology. Moreover, in view of the higher potential for knowledge spillovers, horizontal MNEs may take stronger action to prevent knowledge spillovers from occurring. Consequently, the technological stance of the host country becomes vital for determining which type of FDI yields the highest knowledge spillovers. Likewise, host country characteristics such as intellectual property rights protection are important for establishing knowledge spillovers from FDI, as well as the ownership structure of the MNEs foreign venture.

The model we employ has some relation to other models in the literature on knowledge spillovers. Specific aspects of our model can be found in Müller and Schnitzer (2006) and in Smeets and de Vaal (2006). The novelty of our model is that we combine the relevant aspects for knowledge spillovers to sketch a full(er) picture of knowledge spillovers from FDI, and that we endogenise the difference between knowledge spillovers from horizontal and vertical FDI. Furthermore, a novelty of our framework is that we include strategic behaviour on part of the MNE in view of knowledge spillovers from FDI.

The structure of the paper is as follows. Section 2 discusses knowledge spillovers from FDI and how it relates to the type of FDI involved. Section 3 presents our basic model for knowledge spillovers from FDI. Section 4 applies the model to analyse the differences in knowledge spillovers between vertical and horizontal FDI. Section 5 concludes.

2 Knowledge spillovers and types of FDI

2.1 Factors enhancing knowledge spillovers

In general, the possibilities for host economies to profit from knowledge spillovers from FDI through MNEs is related to their absorptive capacity and their level of technological advancedness. To increase the potential for knowledge spillovers, the technology of the host country should be less advanced than that of the MNE. Technological backwardness enhances knowledge spillovers. At the same time, the host country will need a minimum of technology to be able to absorb the technology of the MNE. This is necessary to assimilate the technology into the existing technologies of local firms. The smaller the difference becomes, the higher this absorptive capacity will be (Castellani and Zanfei, 2006; Smeets, 2009). Absorptive capacity and backwardness therefore both depend on the technology level of the local firm *relative* to the technology level of the MNE. This implies that, given a certain level of knowledge with local firms, also the level of technology employed by the MNE is important. This may vary with the type of MNE, for instance horizontal and vertical MNEs, as we will discuss later. Another issue is that the technology level of the MNE and of local firms will not be independent. To be able to produce in the host country, local workers should have sufficient skills to work with the MNE's technology. If local labour skills are low, the MNE is likely to transfer a lower level of technology (Kokko and Blömstrom, 1995; Wang and Blömstrom, 1992).[1]

MNEs are seen as an important source of technological spillovers, primarily because the channels through which technologies may spill over require spatial proximity (Girma and Wakelin, 2007). The three main channels that have been identified are: demonstration and imitation effects, labour mobility and backward and forward linkages (Castellani and Zanfei, 2006). In case of *demonstration effects*, the MNE demonstrates that a certain technology or practice is suitable in the host country, indirectly providing information about the costs and benefits of the new technology and the risks that are involved. Local firms become aware of the possibilities and can imitate the technology, for example through reverse engineering or through informal contacts. This channel is only relevant if the MNE is present in the country, since local firms have to be able to closely observe the MNE. Furthermore, local firms need to know whether the particular technology is feasible given the conditions in the country. In case of *labour mobility*, employees that were trained by the MNE may move to a local firm, taking their newly acquired knowledge with them. If the wages received in the new firm do not fully reflect this, a positive technological spillover takes place. Not only knowledge about production techniques can be brought in by a firm, but also managerial skills and 'business sense' are important. Moreover, this channel works best if the MNE is present in the country, since mobility of local workers across national borders is limited. In case MNE technologies spill over to local firms through *backward and forward linkages,* a distinction must be made between technological spillovers and technology transfer. The MNE could, for instance, transfer knowledge to its suppliers to improve the quality of its inputs. Since the knowledge is transferred on purpose, this is not a knowledge spillover but a knowledge transfer[2] (Castellani and Zanfei, 2006; Meyer, 2004). However, it would not be likely that the local firm fully compensates the MNE, since it can use the knowledge also in its interaction with other firms (Blömstrom et al., 1999). If the MNE is not compensated for the use of this knowledge in the interaction with others, a knowledge spillover has taken place. Technological spillovers will then be a consequence of technology transfers (Smeets, 2009). Also linkages are mainly local in nature, since this reduces transport costs and facilitates communication between the local firm and MNE.

The effectiveness of these spillover channels is influenced by several factors. Intellectual property rights protection is important for all kinds of spillover channels. If technologies reach the local firms but these firms are not allowed to use these technologies in their

[1] Yeaple (2003) indeed finds this relationship for U.S. outward foreign investments.

[2] It is important to distinguish spillovers from transfers in its own right. To the extent that a local firm acquires technological knowledge from the MNE beyond the scope of a market transaction or without fully compensating the MNE, a spillover has taken place. If, by contrast, the technology flow is the result of the MNE licensing a particular technology to a host firm or from transferring knowledge to increase input quality of inputs, the term technology transfer is appropriate.

production, the spillover channels do not lead to actual spillovers. However, the existence of strong intellectual property rights can also alter the behaviour of MNEs, since the risk of technological spillovers is reduced. Spillovers through labour mobility is more likely if the MNE hires a large amount of local workers and if there are many local firms interested in the local worker after it has received a training from the MNE. More specifically, firms that are active in the same industry as the MNE will be most interested, since they are most likely to be able to use the technologies in a profitable way (Görg and Strobl, 2005). Likewise, MNEs will be more willing to establish local linkages if they benefit from these linkages. For example, backward linkages are positively affected by the technical capability of potential local suppliers (Blömstrom et al., 1999). If suppliers are able to offer high-quality inputs to the MNE, the MNE will be willing to source its inputs locally. Linkages can be crucial to access the resources that are present in the host country, like labour, suppliers, markets, et cetera. A business network helps the firm to take advantage of the host country's resources. The more resources the MNE needs from the host country, the more local linkages it will establish. However, if the MNE is only looking for cheap labour and does not need other resources from the host country, it will not establish a large business network, so linkages would be smaller. In that case, the firm operates in an 'enclave'. (Chen et al., 2004; Lall, 1980; Smeets, 2009). This also has consequences for the likelihood of technological spillovers through backward and forward linkages, as well as for intra-industry spillovers through demonstration and imitation. If the MNE operates in an 'enclave', local firms do not have the opportunity to observe its technology. However, if the MNE has a large local network, spillovers through imitation and demonstration become more likely.

Establishing a local network can be costly though. Especially if the host country is very different from the home country, these costs will be high (Barkema and Vermeulen, 1997). Therefore, participating in an international joint venture could be beneficial for the MNE. International joint ventures can decrease the costs of establishing a local network, since the local partner already has a local network. If the host country is very different with respect to institutions, culture, and/or consumer preferences, participating in a joint venture can lead to a substantial decrease in costs of setting up a local network. The firm benefits from the knowledge of the local partner. However, joint ventures also enhance spillovers to local firms, especially if it is not possible to write contracts that fully protect these technologies. An international joint venture may thus increase spillovers through the direct contact with local firms. Likewise, shared ownership will affect the effectiveness of spillover channels. International joint ventures may establish more upstream and downstream linkages because the local partner already has a local network, whereas a wholly owned subsidiary has to take large efforts to develop such a network. This local network may also lead to increased contact between the local firm and the MNE, giving local firms the opportunity to observe the technologies and imitate them. Furthermore, the local partner is often responsible for the hiring policies. Since the local partner is less concerned with technological spillovers, they will have less incentives to prevent workers from leaving. Technological spillovers through worker mobility are therefore more likely (Javorcik and Spatareanu, 2008).

Technological spillovers can be costly for the MNE, giving them an incentive to try to reduce them. For instance, if the MNE sells its products on local markets, technological spillovers could lower future profits because of a decreased competitive advantage (Blömstrom et al, 1999). To prevent this, the MNE can decide to reduce their technology level by transferring less sophisticated technologies to the host country. The magnitude of the reduction depends on the effectiveness of spillover channels. The higher the effectiveness of spillover channels, the larger this reduction will be. For example, if intellectual property rights protection is weak, the effectiveness of spillover channels becomes high and the MNE will transfer less sophisticated technologies to the host country. As a result, the potential for technological spillovers decreases. Also if an MNE participates in an international joint venture, the effectiveness of spillovers channels increases. Again, the MNE will be less willing to transfer sophisticated technologies and the potential for technological spillover decreases. In both cases, the effectiveness of spillover channels has a negative effect on the potential for spillovers. However, by itself, the effectiveness of spillover channels has a positive effect on spillovers. Hence, the overall effect on spillovers of a change in the effectiveness of spillover channels is ambiguous (Smeets, 2009).

Moreover, if absorptive capacity is low, a lower technology level can lead to an increase in absorptive capacity, increasing spillovers. Consequently, the MNE might decide to transfer more sophisticated knowledge to prevent technological spillovers, since the more backward the local firm is compared to the MNE, the lower absorption will be. The costs to the MNE of transferring less sophisticated technology will be higher the smaller the difference between the technology level of the MNE and the local firms, or the stronger market competition. In that case, the MNE needs its firm-specific advantages to compete with other firms. Not transferring its firm-specific advantages leads to a profit loss (Blömstrom et al., 1999, Kokko and Blömstrom, 1995).

MNEs can also try to reduce the effectiveness of spillover channels. In the case of spillovers through labour mobility, such could be done by paying higher wages. If the wage the local firm is willing to pay to the worker is higher than the wage the MNE pays, the worker has an incentive to leave the MNE. So, the MNE can reduce the risk of spillovers by offering a higher wage than the local firm does. However, if the local firm expects to gain a lot if it hires the local worker, the local firm will offer a high wage. If the costs of preventing the worker to leave are higher than the losses as a result of technological spillovers, the MNE will let the worker go and a technological spillover could take place (Fosfuri et al., 2001). MNEs can also influence the effectiveness of spillover channels by reducing the amount of linkages and becoming less involved in local networks. However, since these linkages and the local network were established to benefit from the resources the host country has to offer, this will be costly. Finally, to prevent spillovers, the MNE can choose a different ownership structure.

2.2 Horizontal versus vertical FDI

An important aspect regarding knowledge spillovers from MNEs is their heterogeneity, for instance the distinction between horizontal FDI and vertical FDI. In the case of horizontal FDI, a firm wants to sell its products in a foreign country, and decides to open a subsidiary in this country. In the case of vertical FDI, a firm opens a subsidiary in the foreign country to gain efficiencies in its value added chain. Firms will choose to engage in horizontal FDI if the costs of transporting its products and the cost of not being physically present in the host country are smaller than the loss of plant economies of scale and the extra fixed costs. Furthermore, the firm will not license if it wants to keep its firm specific knowledge to itself. Firms will choose to engage in vertical FDI if the difference in factor costs between the home and the host country is large enough, and the costs of outsourcing are larger than the benefits of outsourcing. (Barba Navaretti and Venables, 2004; Ethier, 2000).

Since the motive and the considerations to engage in FDI differ between vertical and horizontal FDI, spillovers will also differ. If a horizontal MNE invests in a country, its revenues should be high enough to be able to incur the high costs of engaging in FDI. They need to have a substantial competitive advantage over local firms to acquire a large enough market share. Therefore, to compete successfully with local firms, which have more knowledge of local markets, consumer preferences and business practices, the horizontal MNEs needs to transfer part of its knowledge capital to its subsidiary in the host country (Blömstrom and Kokko, 1998). This knowledge capital creates a competitive advantage for the MNE, but is also interesting for local firms in view of potential knowledge spillovers.[3]

The case of vertical FDI is somewhat different. To countries that are low-skilled labour abundant, vertical MNEs will transfer low-skilled labour intensive production, retaining the high-skilled labour intensive parts of production at home. In contrast to horizontal FDI, only the less technologically advanced parts of production will enter the

[3]The fact that horizontal multinationals do not license their knowledge capital and brand to a foreign party may serve as proof of their having valuable knowledge capital. By establishing a subsidiary, they prefer to keep this knowledge capital internal, but the risk of knowledge spillovers remains.

host country. Moreover, whereas horizontal MNEs invest in a country to exploit their competitive advantage, vertical MNEs invest to create a competitive advantage. As a result, the vertical MNE transfers less knowledge capital abroad, reducing the potential for knowledge spillovers.

The question arises whether or not local firms still have anything to learn from vertical MNEs. If they transfer only less technological advanced parts of production, they might be on the same technology level as local firms. In many instances, local firms may indeed have the same technology level as the MNE. However, there will also be a range of host country technology and efficiency levels for which local firms could still learn from vertical MNEs. Whereas the vertical MNE only produces low-skilled labour intensive products in the host country, it will try to do this in the most efficient way. If they are more efficient than local firms, technological spillovers can take place. Furthermore, what is considered as low-skilled labour intensive outward FDI for an advanced country, could be relatively high-skilled labour intensive FDI for a less-developed country (Lall et al., 2007).

If the technology level of local firms is much lower than the technology level of the vertical MNE, the MNE is also more likely to choose to set up a plant of its own than to outsource production. The further the expertise of the local firm is from the product the MNE demands, the larger will be the investment local firms make to produce those inputs. If contracts are incomplete and outside options are limited, a hold up problem arises and local firms will underinvest to protect their bargaining power (Grossman and Helpman, 2003). From that perspective, a larger technological gap will enhance vertical FDI. Moreover, the benefits of outsourcing decrease when the technology gap is larger. The productivity advantage of outsourcing consists of better information about local conditions and plant-level economies of scale. A too low technology of local firms erodes this advantage, stimulating vertical FDI.

Vertical MNEs thus transfer less advanced knowledge than horizontal MNEs, but for low levels of host country technology vertical MNEs still create a potential for technological spillovers. This will have interesting implications if absorptive capacity and backwardness are taken into account. As argued, technological spillovers will only take place if the local firm is able to absorb the technologies of the MNE. This means that MNEs with the most advanced technologies do not always generate the largest spillovers. If local firms have low absorptive capacity, vertical MNEs create larger technological spillovers than horizontal MNEs. On the other hand, the potential for technological spillovers will be higher in the case of horizontal FDI. If the level of technology of local firms is close to the vertical MNE, there is not much potential for technological spillovers from vertical FDI. However, since the technology level of horizontal MNEs is higher, there is still a potential for technological spillovers from horizontal FDI. So, both the absorptive capacity and the backwardness of local firms determines whether technological spillovers from horizontal FDI are larger than vertical FDI or the other way around.

Vertical and horizontal MNEs also differ with respect to the effectiveness of spillover channels. Vertical MNEs will create less technological spillovers through imitation and demonstration and linkages. As argued, technologies only spill over through these channels if the MNE is embedded in the country. MNEs that are only looking for cheap labour, as in the case of vertical FDI, are less likely to establish a local network and operate in 'enclaves', whereas horizontal MNEs are more embedded in the country (Chen et al., 2004; Lall 1980; Smeets, 2009). As a result, horizontal MNEs provide more spillover channels for technologies to spill over than vertical MNEs.

However, the change in behaviour of the MNE as a result of spillovers will also differ between horizontal MNEs and vertical MNEs. Horizontal MNEs are more likely to make a genuine effort to reduce spillovers. Spillovers are especially costly if the MNE directly competes with local firms on the product market, which is the case for horizontal MNEs. The costs of reducing its technology level also differs between horizontal and vertical MNEs, however. A lower technology level results in a smaller competitive advantage for the horizontal MNE. In this case, the extent of competition and the initial technological distance between the MNE and the local firms is important. In the case of vertical FDI, a lower technology level means that the quality of part of its production process decreases. This can lead to a final product of lower quality, which makes it more difficult to compete on world markets.

3 Modelling knowledge spillovers from FDI

The previous section has argued that technological distance between local firms and MNEs affects both knowledge spillover potential and absorptive capacity from FDI. Moreover, absorptive capacity and the effectiveness of spillover channels co-determine the extent by which a local firms can profit from potential knowledge spillovers. In turn, the effectiveness of spillovers is affected by ownership structure and intellectual property rights protection. Furthermore, we have argued that spillovers may lead to a loss of competitive advantage and future profits for the MNE, inducing the MNE to reconsider how much knowledge it will transfer abroad. Likewise, it has an incentive to reduce the effectiveness of spillover channels.

We will now translate these outcomes into a mathematical model that can be used to asses the differences between vertical and horizontal FDI in generating knowledge spillovers. As explained, technological spillovers only take place if there is a potential for spillovers. We assume that the potential P relates positively to the difference in the technology level of local firms (T_L) and the technology level the MNE employs in the host country (T_M) and that it is nonnegative ($T_M \geq T_L$):

$$P = T_M - T_L \geq 0. \tag{1}$$

Actual spillovers will be smaller than the potential spillovers as a result of limited absorptive capacity of local firms and the effectiveness of spillover channels. Absorptive capacity is related to technological distance as well. Using A to denote absorptive capacity, we assume:

$$A = 1 - b(T_M - T_L) \qquad\qquad 0 \leq b \leq 1. \tag{2}$$

To keep the analysis tractable we assume a linear relationship and require $A \geq 0$. Consequently, for local firms to absorb knowledge, technological distance should not be too large: $TD \equiv T_M - T_L < 1/b$.

Regarding the spillover channels we assume that their effectiveness depends on several aspects. First, it depends on the effectiveness of the different channels involved, i.e. worker mobility, linkages and imitation and demonstration effects. The effectiveness of these channels will be summarized by F. Second, ownership structure is important (O). Shared ownership affects the amount of spillovers reaching the local partner firm, but also has an indirect effect through its impact on the MNE's local network, the importance of linkages and the possibilities for imitation. This indirect effect will be stronger, the less effective spillover channels are with full ownership. Third, we model a relationship with intellectual property rights protection (IPP). The stronger intellectual property rights, the less effective the spillover channels.

Using H to denote the effectiveness of the spillover channels that results, we get:

$$H = [F + (1 - O)(1 - F)]\,(1 - IPP)\,, \tag{3}$$

where $0 < F < 1$ and $0 < IPP < 1$. Intellectual property rights protection is strong (weak) if IPP is high (low). Moreover, we constrain MNE's ownership of its venture abroad to be complete ($O = 1$) or equally shared with a local partner ($O = 1/2$). Consequently, $0 < H < 1$.

Actual spillovers can be seen as the product of spillover potential, absorptive capacity and the effectivenes of spillover channels:

$$S = P \cdot A \cdot H = TD[1 - b \cdot TD]H, \tag{4}$$

where we recall that $TD > 0$ is the technical distance between the MNE's technology and that of local firms. Similar to Smeets and de Vaal (2006), there is an inverted u-shaped relationship between technological distance and the amount of spillovers. We assume that local firms can only absorb new technologies if $T_L > 0$ and therefore require $S < 0$ for $T_L = 0$. If $T_{\max}$ is the highest level of technology the MNE could employ abroad, this implies:

$$T_{\max} > 1/b \geq 1. \qquad \text{(Condition 1)}$$

As a result, the inverted u-shape lies fully within the range of the model and its width is $1/b$.[4] If the MNE would not take any action to prevent knowledge spillovers to occur, (4) would imply $S = TD_{\max}[1 - b \cdot TD_{\max}]H$, with $TD_{\max} \equiv T_{\max} - T_L$. Maximum spillovers are $S = H/4b$ at a local technology level of $T_L = T_{\max} - 1/2b$. Before that point, absorptive capacity dominates spillover potential, and vice versa beyond spillover maximum.

Since spillovers are costly to the MNE, it will try to prevent them. To that end, the MNE may reduce its technology level abroad to $T_M < T_{\max}$, it may reduce the effectiveness of spillover channels, or both. As a result, T_M and H are endogenous and depend on a cost-benefit analysis on part of the MNE. Following Müller and Schnitzer (2006), we assume that spillovers have a negative effect on the MNE's profits:[5]

$$\pi = \pi_0 - mS, \qquad (5)$$

where π_0 represents MNE profits if there were no spillovers and where m is the extent by which spillovers affect profits. The larger m, the bigger the incentive for the MNE to reduce spillovers, . The marginal benefit of lowering T_M below $T_{\max}$ is implicit in (5), taking into account(4):

$$\frac{d\pi}{dT_M} = -mH[1 - 2b \cdot TD]. \qquad (6)$$

Reducing its technology below $T_{\max}$ will not always increase MNE profits. The reason is that a lower technology level decreases the potential for knowledge spillovers, but at the same time enhances local firm's absorptive capacity.[6] Only if $d\pi/dT_m$ is negative at $T_{\max}$, will the MNE consider lowering its technology level abroad. From (6) it follows that this is the case if, and only if, $TD_{\max} \leq 1/2b$.

Reducing T_M is also costly for the MNE, for instance because it reduces its competitive

[4] $S = 0$ if $T_L = T_{\max}$ (upper bound) or $T_L = T_{\max} - 1/b > 0$ (lower bound).

[5] Grünfeld (2006) represents this effect in a Cournot duopoly game in which spillovers have a negative effect on equilibrium levels of output.

[6] This is in contrast to in Müller and Schnitzer (2006), who do not take into account absorptive capacity. In their model a lower technology level always leads to less spillovers. Grünfeld (2006) takes absorptive capacity effects into account, but assumes that MNE technology is entirely different from the technology of local firms. Potential spillovers are then fully determined by the absolute technology level of the MNE, and not by technological distance.

advantage in local or international markets. We model the profit loss (PL) that results from a lower technology level by:

$$PL_T = (T_{\max} - T_M)^2 X / TD_{\max}, \tag{7}$$

where X indicates the costs of reducing T_M and where we assume that the profit loss is quadratic in the reduction achieved. The term is divided by $TD_{\max}$ to guarantee that the MNE never reduces its technology level to the technology level of the host country. A sufficient condition for $T_M > T_L$ is[7]:

$$\frac{X}{m} > \frac{H}{2}. \qquad \text{(Condition 2)}$$

The optimal level of T_M becomes:

$$T_M = \frac{\frac{X}{m} T_{\max} - bH \cdot T_L \cdot TD_{\max} - H \cdot TD_{\max}/2}{\frac{X}{m} - bH \cdot TD_{\max}}. \tag{8}$$

By definition, T_M is constrained to be lower or equal than $T_{\max}$. Furthermore, if condition Condition 2 holds, the MNE never reduces T_M to T_L, which implies $TD > 0$ always. Moreover, and importantly, the MNE will only lower T_M below $T_{\max}$ if $0 < TD_{\max} \leq 1/2b$.[8] That is, beyond the level of local technology for which spillovers reach a maximum. If the initial technological distance between MNE and local firms is too large, the lowering of MNE technology will increase the local firm's absorption capacity by more than it reduces spillover potential. If $TD_{\max}$ is zero, spillover potential is zero and the MNE chooses $T_M = T_{\max}$.

The MNE can also affect spillovers by reducing the effectiveness of the spillover channels.[9] Let F_0 be the effectiveness of spillover channels if the MNE does not take any action, while F is the optimal effectiveness of spillover channels from the perspective of the MNE. Accordingly, the change in profits at $F = F_0$ becomes:

$$\frac{d\pi}{dF} = -m \cdot TD[1 - b \cdot TD][1 - IPP]O < 0. \tag{9}$$

Reducing F below F_0 therefore always yields benefits to the MNE so that $F \leq F_0$. Whether or not the MNE actually tries to reduce F depends on the costs involved. To

[7] To be obtained by requiring $d\pi/dT_M - dPL/dT_M$ to be positive at $T_M = T_L$.

[8] This is in contrast to Javorcik and Spatareanu (2008), who argue that MNEs engaging in an international joint venture will lower technology levels to reduce spillovers.

[9] This is for instance modeled by Fosfuri et al. (2001) for the case of spillovers through worker mobility. In their model the MNE could decide to decrease the effectiveness of this spillover channel by offering a higher wage. The MNE may also affect the other two spillover channels after the MNE has decided on the ownership structure. For simplicity, however, the ownership structure is assumed to be exogenous.

reduce the effectiveness of spillover channels, the MNE may have to pay higher wages, import inputs rather than source locally or refrain from engaging in local networks. As it becomes more and more difficult to decrease the spillover channels that remain, we assume that these costs increase quadratically in $F_0 - F$:

$$PL_F = Z \cdot (F_0 - F)^2, \tag{10}$$

with $Z > 0$ is a general costs parameter. Equating the marginal costs of reducing spillover channel effectiveness to its marginal benefits, gives:

$$F = F_0 - \frac{m \cdot TD[1 - b \cdot TD][1 - IPP]O}{2Z}, \tag{11}$$

which is smaller than F_0 by condition Condition 1. A sufficient condition for optimal F to be positive is:

$$4bF_0 > O(1 - IPP)m/2Z. \qquad \text{(Condition 3)}$$

If Condition 3 holds the MNE will not eliminate all spillover channels, even when spillovers are at its maximum.[10] Logically, this is more likely the higher the costs of reducing spillovers (high Z, high F_0) and the lower the benefits of reducing the effectivity of spillover channels (low O, high IPP, low m, high b).

The extent by which the MNE desires to reduce F also depends on the technology level it chooses to employ abroad. Moreover, as we have seen, its desire to reduce T_M below $T_{\max}$ depends on the initial technical distance between the MNE and local firms $TD_{\max}$. Consequently, the MNE may or may not reduce T_M which has consequences for the level of F chosen as well. To illustrate this we show in Figure 1 spillovers for four different scenario's. The curve S(F_0,$T_{\max}$) gives spillovers in case the MNE does not optimize and produces abroad with $T_{\max}$ and F_0. The curve S(F_0,T_M) gives spillovers if the MNE optimizes T_M, but not F. The curve S(F,$T_{\max}$) depicts spillovers when the MNE optimizes F, but not T_M. The curve S(F,T_M), finally, gives the situation when the MNE optimizes both T_M and F. Though all curves are drawn for the case of full ownership, their curvature equally applies to share ownership. A mathematical substantiation of the different curves is given in the Appendix.

As noted, the MNE will only adjust its level of technology if $TD_{\max} \leq 1/2b$. Else it will choose $T_M = T_{\max}$. This implies that S(F_0,T_M) only differs from S(F_0,$T_{\max}$) if $T_L \geq T_{\max} - 1/2b$, as drawn, and spillovers remain at a maximum at $T_L = T_{\max} - 1/2b$.

[10] The condition is derived by evaluating (11) at the technical distance for which the marginal benefits of reducing F are at a maximum. From (9) is follows that this is the case when $TD = 1/2b$, the point where spillovers are maximal.

To the right of this maximum, the reduction of the technology level of the MNE is largest at intermediate technological distances (see Appendix). Intuitively, this can be explained by the fact that both at large and small technological distances, a reduction of technology only affect spillovers marginally. At large distances because of low absorptive capacity of local firms, at small distances because of low spillover potential.

If the MNE only reduces the effectiveness of spillover channels, spillovers decrease at all levels of local technology. This follows directly from (4) and (11), which for given $T_{\max}$ and b only depends on H. The decrease will be highest, the closer local technology is to $T_{\max} - 1/2b$. Curve S(F,$T_{\max}$) represents this effect. However, the reduction of the effectiveness of spillovers could be so large that the initial maximum becomes a local minimum. Whereas a deviation of T_L from $T_{\max} - 1/2b$ by itself decreases spillovers, it also lower the reduction of F. If the latter effect is strong, the curve may become 'twin peaked'. A formal condition settling that this will not occur is:

$$4bF_0 > O(1 - IPP)m/Z. \qquad \text{(Condition 4)}$$

The condition resembles Condition 3, but is clearly stronger. The right-hand-side is the benefit-cost ratio of reducing the effectiveness of spillover channels. If this ratio relatively high, the reduction of the effectiveness of spillover channels is large, potentially leading to "twin peaks". Whether or not this is the case depends on the shape of the original spillover curve, which is for a large part determined by b and F_0.

Finally, when the MNE optimizes both T_M and F, curve S(F, T_M) arises. As long as $T_L < T_{\max} - 1/2b$, this curve is the same as S($F, T\max$), since then $T_M = T_{\max}$. At larger values of T_L the MNE starts reducing its technology level, which has a negative effect on spillovers. As a result, F becomes higher for each value of T_L, compared to the case in which the MNE did not change its technology level. This has a positive effect on spillovers. However, this positive effect is weaker than the negative effect of the reduction of T_M. As a result S(F, T_M) lies below S($F, T_{\max}$) for $T_L > T_{\max} - 1/2b$, see Appendix.

(Insert Figure 1 about here)

4 Vertical and horizontal FDI

In Section 2 we have highlighted the main differences between horizontal FDI and vertical FDI in relation to knowledge spillovers. The main differences that were identified related to the technology level each type of FDI would use abroad, the effectivity of spillover channels and the costs and benefits of reducing spillovers. In this section, we will adapt our model to take these differences into account.

As argued, an important difference between horizontal and vertical FDI is that $T_{\max}$, is smaller for vertical FDI than for horizontal FDI, see also Smeets (2009), Beugelsdijk et al. (2008) and Driffield and Love (2007). Using superscripts V and H to distinguish between vertical and horizontal FDI, we assume:

$$T_{\max}^{V} = nT_{\max}^{H} \qquad\qquad 0 < n < 1. \tag{12}$$

As before, both curves are inverted u-shapes, with lower and upper bounds at, respectively, $T_L^k = T_{\max}^k - 1/b > 0$ and $T_L^k = T_{\max}^k$ $(k = H, V)$. Both the lower and the upper bound are therefore higher for horizontal FDI than for vertical FDI. The width of the shapes is the same for both types of FDI, equalling $1/b$. To have a range of values for T_L for which both horizontal FDI and vertical FDI yields positive spillovers, we require $T_{\max}^V > T_{\max}^H - 1/b$. Hence,

$$(1-n)T_{\max}^{H} < 1/b. \qquad\qquad \text{(Condition 5)}$$

To make the analysis consistent with zero spillovers at $T_L = 0$ (Condition 1), this implies $1/2 < n < 1$.

Also the effectiveness of spillover channels differs between horizontal and vertical FDI. Horizontal MNEs create more linkages and have a larger local network, affecting the value of F_0. Also m, the profit loss due to spillovers, will differ. Since horizontal MNEs compete directly with local firms, whereas competition for vertical MNEs is only indirect through factor markets, spillovers are more costly for horizontal MNEs. Hence,

$$F_0^V < F_0^H \qquad \text{and} \qquad m^V < m^H. \tag{13}$$

Finally, the costs of reducing spillovers by decreasing its technology level will be different for horizontal MNEs than for vertical MNEs. A lower technology level reduces the quality of the MNE product and/or increases the costs to produce this product. As a result, it becomes harder to compete with other firms. Since it is likely that firms in the MNE's home country are more competitive than firms in the host country, the costs of reducing its technology level are higher for vertical MNEs than for horizontal MNEs: $X^V > X^H$. This reinforces the effect of the difference in m, since it is the ratio of cost and benefits that determines the optimal technology level in equation (8). Hence,

$$\frac{X^V}{m^V} > \frac{X^H}{m^H}. \tag{14}$$

Clearly, these differences between horizontal and vertical FDI imply differences in spillovers. Ignoring for now the MNE's reaction on the threat of spillovers, we depict in Figure 2 total spillovers from horizontal FDI and vertical FDI in the case of full ownership.

It shows that for low technology levels of local firms spillovers from vertical FDI are largest, and that for high technology levels of local firms spillovers from horizontal FDI are largest. These results are in contrast with the earlier literature, which sees spillovers from horizontal FDI larger due to a higher potential for spillovers. Figure 2 shows this is not the case when taking into account absorptive capacity as well.

> **Result 1**: If horizontal FDI entails the use of a higher technology level abroad than vertical FDI, ceteris paribus implying a higher potential for knowledge spillovers from horizontal FDI, taking into account the absorptive capacity of host countries implies that the actual difference in knowledge spillovers between both types of FDI depends on the host country's technology level T_L. Vertical FDI leads to more spillovers than horizontal FDI when T_L is low and vice versa when $T_L$is high.

A sufficient condition for vertical FDI to yield higher spillovers than horizontal FDI is $T_L < T^H_{\max} - 1/b$ for then absorptive capacity is zero for horizontal FDI. A sufficient condition for horizontal FDI to yield higher spillovers is $T_L > T^V_{\max}$ for then spillover potential is zero for vertical FDI. The level of T_L for which both curves intersect, $\bar{T}_L$, is implicit in:

$$\frac{(T^H_{\max} - \bar{T}_L)}{(nT^H_{\max} - \bar{T}_L)} \frac{H^H}{H^V} = \frac{[1 - b \cdot (nT^H_{\max} - \bar{T}_L)]}{[1 - b \cdot (T^H_{\max} - \bar{T}_L)]}.$$

Evaluating the total differential of this equation at the point of intersection shows that $\bar{T}_L$ increases when H^V goes up or H^H goes down. If the relative effectivity of the vertical spillover channels increase, T_L must increase to bring spillover levels closer to the maximum for horizontal spillovers. $\bar{T}_L$ also increases when b goes up. A higher b increases the burden of being further away from the MNEs technology level, which reduces spillovers more when absorptive capacity dominates spillover potential, that is to the left of the maximum of the curve. Consequently, spillovers reduce more for horizontal FDI, implying $\bar{T}_L$ must increase. Similarly, a higher n implies that $\bar{T}_L$ must increase. The effect of a higher $T^H_{\max}$, finally, is ambiguous because it affects both curves similarly.

Figure 2 also reflects the fact that spillover channels are less effective in case of vertical FDI. The maximum amount of spillovers is lower than for horizontal FDI, since a smaller percentage of the potential for spillovers does reach local firms: $S^H = H^H/4b > H^V/4b = S^V$. Shared ownership increases the effectiveness of spillover channels for both horizontal FDI and vertical FDI, increasing spillovers proportionally for both types of FDI for all levels of T_L.

(Insert Figure 2 about here)

Figure 2 does not include the MNE's reaction on spillovers. Since the profit loss due to spillovers is highest for horizontal FDI, $m^H > m^V$, horizontal MNEs will try harder to reduce the effectiveness of spillover channels than vertical MNEs. This implies that even though the initial effectiveness of spillover channels is higher for horizontal FDI, its reaction may imply a lower effectiveness than for vertical FDI. Especially around $T_L = T_{\max} - 1/2b$ this is a genuine possibility.

> **Result 2**: Horizontal MNEs will lower the effectivity of spillovers channels by more than vertical MNEs. As a result, the relative effectivity of spillover channels of horizontal and vertical FDI becomes unclear when the reaction of MNEs to reduce spillover channel effectivity is taken into account.

Furthermore, the horizontal MNE reduces its technology level to a much larger extent than the vertical MNE. The profit loss due to spillovers is higher, while we have also argued that the reduction of technology is less costly for horizontal MNEs. As before, the horizontal MNE only changes its technology level if $T^H_{\max} - 1/2b \leq T_L$. Consequently, the technology level horizontal MNEs employ abroad may be lower than for vertical FDI: $T^H_M \gtrless T^F_M$. Result 1 showed that absorptive capacity mattered for the relative technology level of horizontal and vertical MNEs, now we see that also the difference in reaction is important.

> **Result 3**: When MNEs react to spillovers by lowering their technology levels abroad, this reaction will be stronger for horizontal MNEs than for vertical MNEs. Therefore, if $T^H_{\max} - 1/2b \leq T_L$, T^H_M might be lower than T^V_M, even though the maximum technology level is higher for horizontal FDI than for vertical FDI.

In summary, the shapes of the spillover curves differ between horizontal FDI and vertical FDI for two reasons. First, as a result of differences in the initial effectiveness of spillover channels. Second, as a result of the extent by which MNEs react on spillovers. However, whether spillovers are positive or zero depends on the level of T_L. For either type of FDI, it holds that if the host country's technology level lies between $T^k_{\max} - 1/b$ and $T^k_{\max}$ $(k = H, V)$, technological spillovers will be positive. Moreover, T_L determines for a large part which type of FDI yields highest spillovers. Likewise, the effect of local changes in technology on knowledge spillovers depends on the initial value of T_L and the type of FDI.

This has important implications for governments desiring to attract FDI to benefit from knowledge spillovers. When the host economy's technology level is low, governments might want to attract vertical FDI rather than horizontal FDI, while for high values of local technology governments could better target at horizontal FDI. At intermediate technology levels, both types of FDI lead to positive spillovers, making the right policy choice less clear.

Should governments be able to attract the right type of FDI, our analysis makes clear that providing stimuli to elevate local technology levels may not be a wrong strategy to enhance knowledge spillovers. The amount of spillovers is not necessarily positively correlated with the local technology level — depending on the absorptive-capacity-spillover-potential trade off — while it also depends on the type of FDI one gets on board. At low levels of T_L, for instance, it might be just as efficient to focus on measures attracting vertical FDI to increase local technology levels. Moreover, these spillovers might be just as high as the maximum possible spillovers one could reach from horizontal FDI at high levels of local technology.

At some point, the technology level of the host country might become high enough to be able to benefit from horizontal FDI. In that case, a relatively low technology level is advantageous since the MNE will take less effort to reduce these spillovers. This effect is strongest when intellectual property rights protection is weak, when the costs of spillovers are high for the MNE and when MNE has full ownership. In that case, Condition 4 may not hold and the spillover curve will be as drawn in Figure 3. This complicates the right policy choice. Again, a higher technology level does not automatically lead to higher spillovers. The MNE sees a higher technology level as a threat, and will therefore reduce the effectiveness of spillover channels or its technology level. Therefore, at an intermediate technology level spillovers are lower than at a relatively low technology level. However, at a smaller technological distance, spillovers increase again. Since the potential for spillovers has decreased, the risk of spillovers is lower, so the MNE is less willing to reduce the effectiveness of spillovers channels. Hence, if the technology level of the host country is such that spillovers are at the local minimum, both an increase and a decrease of local technology levels may increase spillovers.

(Insert Figure 3 about here)

Not only T_L affects the extent of spillovers, other host country characteristics are also important. First, the extent of competition in local markets is important for spillovers. If local competition increases, it becomes more costly to reduce T_M and X increases. However, only in the case of horizontal FDI will this be the case. As argued by Blömstrom et al. (1999), the horizontal MNE needs a higher technology level to remain competitive. Consequently, when competition in local markets tighten, horizontal MNEs will increase the level of technology employed abroad, leading to an increase in spillovers.[11] However,

[11] From the Appendix we obtain that $dS/dX = (a_2a_5 + a_3)a_{10}/D$. For $TD_{\max} \leq 1/2b$, $a_{10} > 0$ and

this will only be the case when $T^H_{\max} - T_L < 1/2b$, since only then the MNE desires to reduce its technology level.

> **Result 4:** If the technological distance between local firms and horizontal MNEs is not too large, increased competition in local markets will increase knowledge spillovers from horizontal FDI.

Also the extent of ownership matters for spillovers. By itself, shared ownership increases the extent of spillovers, as it increases the effectiveness of spillover channels, see (3). Moreover, it becomes harder to reduce the effectiveness of spillover channels, since the local partner has a local network which leads to more spillover channels, see (11). For both types of FDI, F will therefore increase when ownership is shared.[12] The MNE could therefore also try to reduce its technology level. This is only possible if $T_{\max} - T_L < 1/2b$, while the effect will be stronger for horizontal FDI than for vertical FDI (Result 3). Since the effectiveness of spillover channels increases but the technology level of the MNE decreases for each level of T_L, the overall effect of shared ownership on spillovers is ambiguous in case $T_{\max} - T_L < 1/2b$.[13].

> **Result 5**: If $T_{\max} - T_L > 1/2b$, knowledge spillovers are higher in the case of shared ownership than in the case of full ownership, since the MNE does not change T_M. If, however, $T_{\max} - T_L < 1/2b$, ownership structure has an ambiguous effect on knowledge spillovers. Since the change in T_M will be larger for horizontal FDI than for vertical FDI (Result 3), the likelihood that shared ownership increases spillovers is larger for vertical FDI than for horizontal FDI.

The policy implication of this result is that if a country wants to encourage international joint ventures, it should take into account the type of FDI it is dealing with. In the case of vertical FDI, the effect will mostly be positive, since the reduction in T_M will be small. In the case of horizontal FDI the effect could be smaller or even negative, since the MNE has strong incentives to reduce its technology level.

A country may also decide to strengthen its intellectual property rights protection. This would reduce the effectiveness of spillover channels per se, see (3), but is also lowers the incentive for MNEs to reduce the effectiveness of spillover channels subdues. The

since we assume $D > 0$, it follows that $dS/dX > 0$ if $a_2 a_5 > -a_3$, which will be the case if Condition 4 holds.

[12] Since $m^H > m^V$, the indirect effect through F is bigger for horizontal FDI than for vertical FDI. From (11) it follows that $\partial F/\partial O < 0$ and $\partial(\partial F/\partial O)/\partial m < 0$. The direct effect of O on H is however indeterminate by Result 2.

[13] Smeets and de Vaal (2006) find that spillovers are always higher in the case of shared ownership than in the case of full ownership. They however do not take into account the effects of a reduction of T_M.

overall effect on the effectiveness of spillover channels is ambiguous. The direct effect is negative, but the indirect effect on H through F is positive. Moreover, the indirect effect is stronger for horizontal FDI than for vertical FDI, as the increase in F will be bigger for horizontal FDI.[14] Through the effectivity of spillover channels, a strengthening of intellectual property rights protection is thus more likely to affect spillovers negatively for vertical FDI. As before, the MNE will also increase its technology level, provided $T_{\max} - T_L < 1/2b$, which effect will be strongest in the case of horizontal FDI (result 3). The overall effect of a strengthening of intellectual property rights therefore becomes ambiguous.

> **Result 6**: If $T_{\max} - T_L > 1/2b$, technological spillovers decrease if intellectual property rights protection increases, since the MNE does not change T_M. However, if $T_{\max} - T_L < 1/2b$, the MNE changes T_M, so the effect of a strengthening of intellectual property rights protection is ambiguous. The change of T_M will be larger for horizontal FDI than for vertical FDI.

5 Conclusion

This paper has analyzed the difference in knowledge spillovers between horizontal and vertical FDI. The difference in such spillovers is driven by important differences between horizontal and vertical FDI. Horizontal MNEs have a higher technology level and a higher effectiveness of spillover channels than vertical MNEs. However, horizontal MNEs have a larger incentive to reduce their technology level and the effectiveness of spillover channels.

The little available literature suggests that horizontal FDI would lead to more spillover than vertical FDI, but as this paper has shown, this is not necessarily the case. By incorporating host country characteristics, absorptive capacity and strategic behaviour by the MNE, a more complicated picture of differences in spillovers from horizontal and vertical FDI emerges. The most important result is that the technology level of the host country for a large part determines whether horizontal or vertical FDI leads to the highest spillovers. Countries with a low technology level are not able to absorb the advanced technologies of horizontal MNEs, but are able to benefit from technological spillovers from vertical MNEs. This is good news for countries with a low technology level. Moreover, since vertical FDI is often meant to exploit low skilled labour in less developed countries, while horizontal FDI mainly targets at developed countries, it is likely that countries will typically attract the type of FDI that is most beneficial given their level of development. Furthermore, a lower technology level does not mean that spillovers are automatically

[14] Since $m^H > m^V$ and from (11) $\partial F/\partial IPP > 0$ and $\partial(\partial F/\partial IPP)/\partial m > 0$.

lower, so the benefits from FDI might be just as high in developing countries as in more developed countries.

Another result of our paper is that if countries want to affect the extent of spillovers, it has to take the type of FDI it is dealing with into account, as well as its own technology level. In the case of horizontal FDI there is more room for policy, since the country can give an incentive to the MNE to increase its technology level or the effectiveness of spillover channels. In the case of vertical FDI, this effect will be weaker. However, MNEs do not always change their technology level and this also depends on the host country's technology level. If a lower technology level has a larger effect on absorptive capacity than on the potential for spillovers, the MNE will realize that reducing its technology level leads to higher spillovers. In that case, it can only reduce spillovers by decreasing the effectiveness of spillover channels. This decrease in the effectiveness of spillover channels will be highest at intermediate levels of absorptive capacity and spillover potential. Local firms can use a large part of the knowledge they receive, so the benefits of reducing the effectiveness of spillover channels are highest for the MNE. These benefits could even be so high, that there emerges a local minimum at this point.

The paper also leads to several testable hypotheses. Does vertical FDI indeed lead to more spillovers than horizontal FDI if the technology level of the host country is large? Do MNEs indeed takes absorptive capacity of local firms into account when deciding on the technology level it will employ abroad? Will MNEs indeed try to influence the effectiveness of spillovers channels? If that is the case, the technology level of the MNE should be higher at large technological distances than at small technological distances. Moreover, the effectiveness of spillover channels should be lowest at intermediate levels of technological distance.

We also see possibilities to extend the model. It has been assumed that the only possibility for the MNE to reduce spillovers is by lowering its technology level or the effectiveness of spillover channels. However, the MNE might also decide to export instead of engaging in FDI to decrease spillovers. Including this decision might be a useful extension of the model. Furthermore, it should be noted that it has been assumed that different technologies are substitutes, that is, one technology is better than the other. However, it might also be the case that the different technologies are complements, so one technology is not necessarily better than the other. In the case of FDI from developed to developing countries, technologies will be most likely substitutes, but in the case of FDI between equally developed countries, technologies might be complements. Although the model predicts that spillovers are small in that case, this result could change if technologies complement each other.

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A Mathematical derivations

To analyse the model when both T_M and F are endogenous, we totally differentiate equations (4), (3) and (8) with respect to S, H and T_M and some relevant exogenous variables, to obtain:

$$\begin{bmatrix} 1 & -a_2 & -a_3 \\ 0 & 1 & -a_5 \\ 0 & -a_9 & 1 \end{bmatrix} \begin{bmatrix} dS \\ dH \\ dT_M \end{bmatrix} = \begin{bmatrix} a_1 & 0 & 0 & 0 \\ a_4 & a_6 & a_7 & 0 \\ a_8 & 0 & 0 & a_{10} \end{bmatrix} \begin{bmatrix} dT_L \\ dIPP \\ dO \\ dX \end{bmatrix}$$

where

$$a_1 = [2bTD - 1]H \qquad a_2 = TD(1 - bTD) = S/H$$

$$a_3 = [1 - 2bTD]H \qquad a_4 = -a_5 = m(1 - 2bTD)O^2(1 - IPP)^2/2Z$$

$$a_6 = (O - 1) - OF + mTD[1 - bTD]O^2(1 - IPP)/2Z$$

$$a_7 = (F - 1)(1 - IPP) - mTD[1 - bTD]O(1 - IPP)^2/2Z$$

$$a_8 = \frac{-bHX(2TD_{\max} - 1/2b)/(mTD_{\max}^2) + (bH)^2}{[X/(mTD_{\max}) - bH]^2}$$

$$a_9 = \frac{bX(TD_{\max} - 1/2b)/(mTD_{\max})}{[X/(mTD_{\max}) - bH]^2} \qquad a_{10} = \frac{-bH(TD_{\max} - 1/2b)/(mTD_{\max})}{[X/(mTD_{\max}) - bH]^2}$$

and where $TD_{\max} \equiv T_{\max} - T_L > TD \equiv T_M - T_L > 0$.

Taking the inverse yields

$$\begin{bmatrix} dS \\ dH \\ dT_M \end{bmatrix} = \frac{1}{D} \begin{bmatrix} 1 - a_5a_9 & a_2 + a_3a_9 & a_2a_5 + a_3 \\ 0 & 1 & a_5 \\ 0 & a_9 & 1 \end{bmatrix} \begin{bmatrix} a_1 & 0 & 0 & 0 \\ a_4 & a_6 & a_7 & 0 \\ a_8 & 0 & 0 & a_{10} \end{bmatrix} \begin{bmatrix} dT_L \\ dIPP \\ dO \\ dX \end{bmatrix}$$

with $D = 1 - a_5a_9$. Though we cannot establish this analytically, we will assume the determinant is positive, thus $a_5a_9 < 1$. Numerical calculations have shown that this is not a strict assumption.

The curvatures in Figure 1 follow from evaluating: $dS/dT_L = a_1 + [a_4(a_2 + a_3a_9) + a_8(a_2a_5 + a_3)]/D$:

- The curvature S(F_0,$T_{\max}$) follows by setting a_5-a_{10} equal to zero, amounting to $dS/dT_L = a_1 \gtrless 0$, which is equivalent to $T_L \lessgtr T_{\max} - 1/2b$ as drawn.

- The curve S(F,$T_{\max}$) depicts spillovers when the MNE optimizes F, but not T_M. By setting a_8-a_{10} zero, it follows that $dS/dT_L = a_1 + a_2a_4 \gtrless 0$. Since $a_4 > 0$ and $a_2 \gtrless 0 \Longleftrightarrow T_L \gtrless T_{\max} - 1/2b$, it follows that the absolute slope of S(F,$T_{\max}$) < the absolute slope of S(F_0,$T_{\max}$), as drawn. Moreover, S(F,$T_{\max}$) lies below S(F_0,$T_{\max}$) since $F < F_0$ and $\partial H/\partial F > 0$.

- The curve S(F_0,T_M) gives spillovers if the MNE optimizes T_M, but not F. By setting a_4-a_7 zero, it follows that $dS/dT_L = a_1(1 - a_8) \gtrless 0$, using $a_3 = -a_1$. The term $1 - a_8 > 0$ by condition 2, implying $dS/dT_L < 0$, since he MNE reduces its technology level only if $TD_{\max} \leq 1/2b$, see equation (6).

  The downward change in S depends on the change in T_M, which varies with T_L:

$$\frac{\partial T_M}{\partial T_L} = \frac{-bHX(2TD_{\max} - 1/2b)/(mTD_{\max}^2) + (bH)^2}{[X/(mTD_{\max}) - bH]^2}.$$

  By Condition 2 this is negative if $TD_{\max} = 1/2b$ and positive if $TD_{\max} = 0$. Consequently, $\partial T_M/\partial T_L$ will be zero for some T_L in between. Since from (4) we know that for $TD_{\max} \leq 1/2b$, $\partial S/\partial T_M = -\partial S/\partial T_L = (1 - 2bTD)H > 0$, dS/dT_L is most negative at $TD_{\max} = 1/2b$ and least negative at $TD_{\max} = 0$ as drawn in Figure 1.

- The curve S(F,T_M), finally, gives the situation when the MNE optimizes both T_M and F. Evaluating dS_T/dT_L for $TD_{\max} \leq 1/2b$, for else the MNE would not change T_M, we note that the sign of the determinant is positive if $a_5a_9 < 1$.Though we cannot establish this analytically, we will assume the determinant is positive. Numerical calculations have shown that this is not a strict assumption Using $a_1 = -a_3$ and $a_4 = -a_5$, noting that $(a_8 - 1) < 0$ by Condition 2, we obtain:

$$\frac{dS}{dT_L} < 0 \text{ if } a_2a_5 > a_1.$$

  For $TD_{\max} \leq 1/2b$, this condition becomes, noting that $2bTD - 1 < 0$: $TD(1 - bTD)\frac{mO^2(1-IPP)}{2Z} < H$, which holds if Condition 4 holds.

Figure 1: Technological spillovers from FDI.

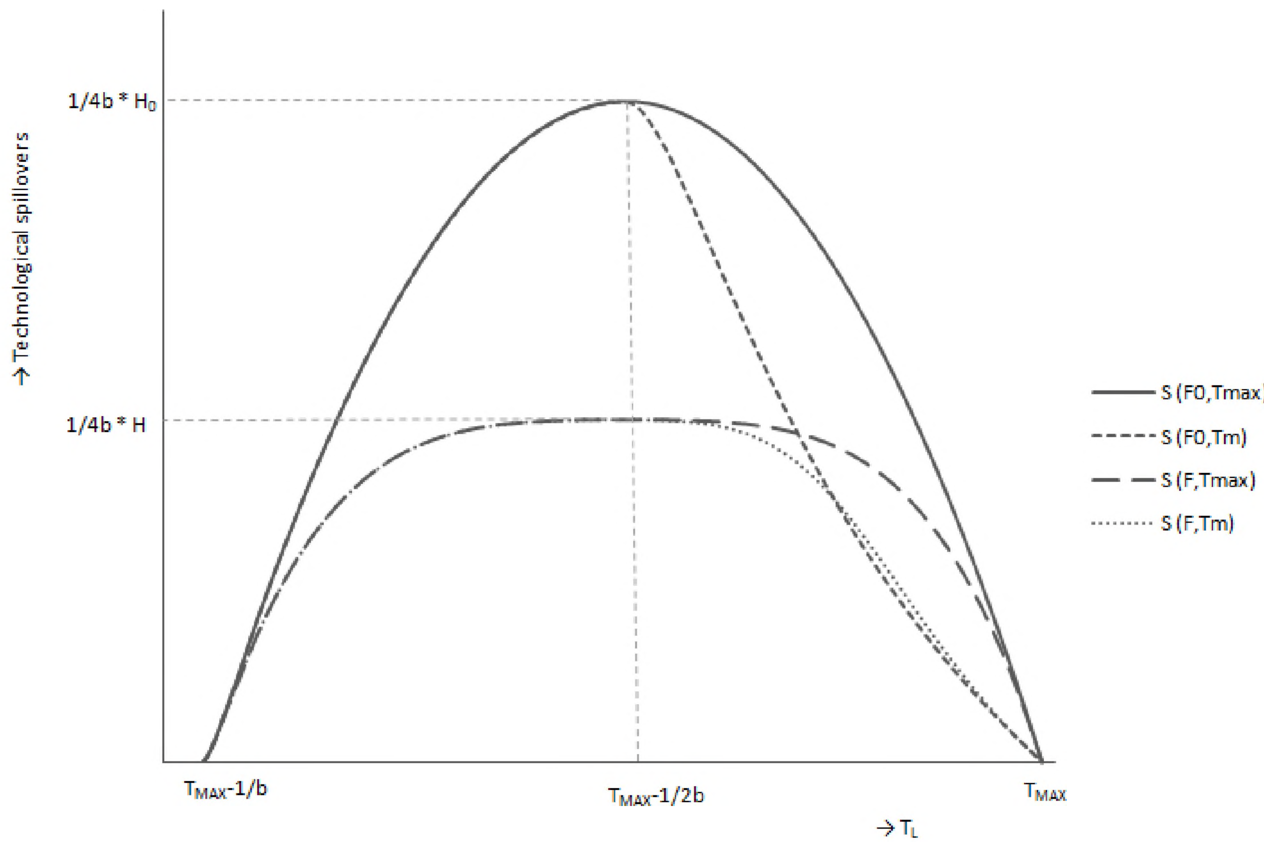

Figure 2: Knowledge spillovers from horizontal and vertical FDI.

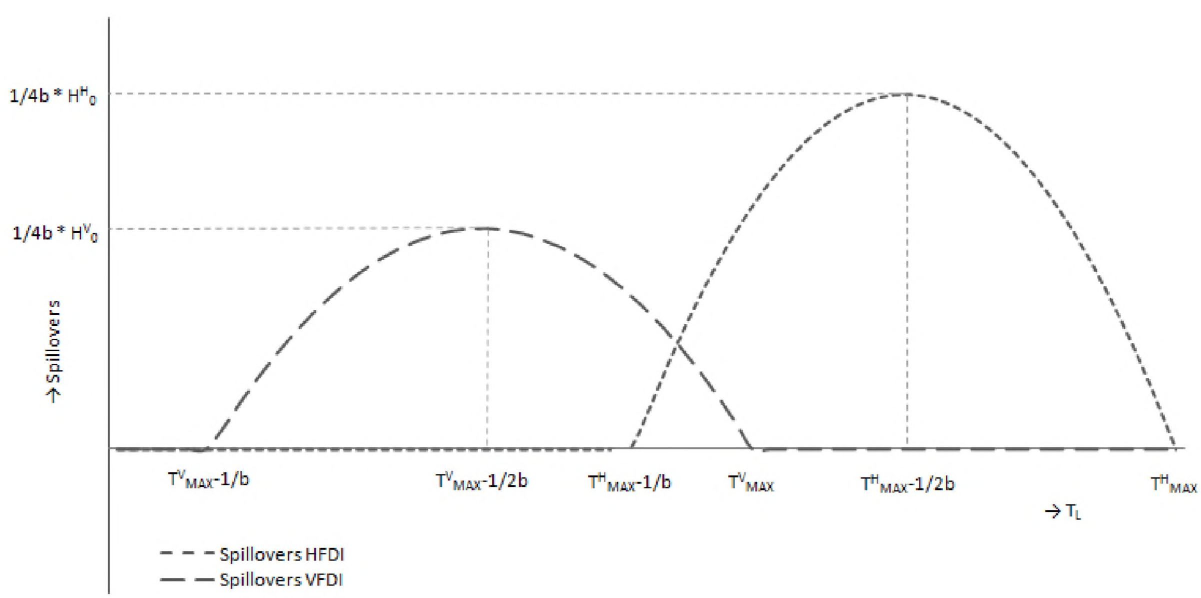

Figure 3: Twin peaks.