R&D and foreign direct investment with asymmetries in knowledge transmission

Maria Luisa Petit
Università di Roma
"La Sapienza"

Francesca Sanna-Randaccio*
Università di Roma
"La Sapienza"

Roberta Sestini
Università di Roma
"La Sapienza"

October 12, 2007

Abstract

In this paper we analyze how firms' R&D investment decisions are affected by asymmetries in knowledge transmission, taking into account different sources of asymmetry such as unequal know-how management capabilities and spillovers localization within an international oligopoly. We find that a better ability to manage knowledge flows incentivates the firm to invest more in R&D. We then introduce geographically bounded spillovers, showing that one-way FDI stimulates the MNE to raise its own R&D, due to both the elimination of transport cost and a greater ability to source. Furthermore, it emerges that when geographical proximity increases the MNE's capability to source local know-how, FDI is more likely to occur.

JEL Numbers: F23, L10, 034.

Keywords: Multinational firms, foreign direct investment, R&D, innovation.

*Corresponding author:Università di Roma "La Sapienza", Dipartimento di Informatica e Sistemistica "A. Ruberti", Via Ariosto 25, I-00185 Rome, Italy. E-mail: `fsr@dis.uniroma1.it`

1 Introduction

Over the last two decades a wide body of theoretical and empirical literature has stressed the effects of knowledge flows (or spillovers) on firms' R&D activity (see, for comprehensive surveys, De Bondt, 1996; Castellani e Zanfei, 2006). This literature suggests that higher spillovers may negatively affect the propensity of firms to undertake in-house R&D activities (the so called own R&D), through a disincentive effect. On the other hand, higher spillovers lead to a cost reduction resulting in a market enhancement effect, representing an incentive for R&D investment. With a few exceptions (De Bondt and Henriques, 1995) these studies are carried out under the assumption that spillovers are symmetric, that is the extent to which firms may source knowledge from each other is similar.

In this paper we aim at relaxing the assumption of symmetric spillovers, considering two situations in which firms may be led to manage external information flows by deliberately increasing incoming spillovers (and/or decreasing outgoing spillovers):

- First, we allow for different know how management capabilities.
- Secondly, we consider the effects of geographical distance as a source of asymmetry, thus exploring the effects of geographically bounded spillovers in an international oligopoly.

As to the first point, the hypothesis that firms generate and receive spillovers to the same extent (that is the symmetry between incoming and outgoing spillovers) obviously precludes the notion that firms are able somehow to manage these information flows. This view has been questioned in the recent literature. Growing empirical evidence indicates that firms exert effort and employ resources in R&D also in order to increase their ability to appropriate the knowledge and technology elaborated by other firms. This behaviour was firstly pointed out by Cohen and Levinthal (1989), when they argued that external knowledge flows are more effective for the innovation process of a firm when the firm itself engages in R&D activities. In other words, firms aim at increasing the amount of incoming spillovers by investing in “absorptive capacity”. In such a scenario it is reasonable that the above predictions as to the disincentive effect of spillovers do not hold true any longer. This is because the desire to assimilate external knowledge flows creates a positive incentive to invest in R&D. Hence, introducing absorptive capacity may lead to an increase in equilibrium industry R&D investment due to the presence of spillovers. Moreover a firm may attempt at increasing its incoming spillovers by voluntarily trading technological knowledge with partners, as it is typical in the research joint venture information-sharing cartels (Kamien et al., 1992). An empirical study by Cassiman and Veugelers (2002) documents that incoming spillovers have a positive and significant effect on the probability of firms cooperating in R&D. In a further study Veugelers (1997) explores in a sample of Flemish companies the closely related issue of the relationship between external sourcing and internal (or in-house) R&D activity, finding that only when one explicitly takes into account absorptive capacity it is possible that cooperative R&D engagements have a significant effect on internal R&D expenditures. This result gives support to the hypothesis of complementarity between in-house R&D and external know-how.

In the theoretical research, however, the effects of absorptive capacity on the incentive to invest in R&D are far from being thoroughly assessed and clear-cut. While Cohen and Levinthal (1989) stressed the positive effect of absorptive capacity on the incentive to invest, Grunfeld (2003) reached the conclusion that this result does not always hold true, as two opposite forces act on the incentive to invest in R&D. On one side the R&D effort is spurred by the necessity to learn from others, while on the other side higher absorptive capacity leads the rivals to invest less. By incorporating absorptive capacity (through an endogenous spillover rate which is function of own R&D) into the d’Aspremont and Jacquemin model, Grunfeld shows that if the market size is sufficiently large, the negative traditional effect of spillovers outweighs the positive learning effect.

As to the second rationale for our investigation, both empirical and theoretical studies have suggested that the distance between the receiver and the generator of knowledge may play an important role. The geographical dimension of know-how transfers is particularly relevant in the analysis of firms' strategies of international expansion. When geographical proximity increases involuntary know-how transfer, one of the reasons that may push firms towards multinational expansion is the possibility to locate subsidiaries near sources of technological innovation. At the same time, domestic firms may take advantage of the closer location of these subsidiaries and absorb more easily and quickly the technological knowledge produced by them.

Also a wide body of empirical literature has shed light on the issue of international spillovers, finding that they tend to be geographically bounded, although the degree of technological localization has sharply fallen over time (see Jaffe et. al, 1993; Criscuolo, 2004; Keller, 2002, 2004). Similar results on the limited geographical scope of spillovers are obtained by studies which use patent citation information to trace the presence of spillovers from foreign subsidiaries to the local economy (for instance, Almeida, 1996). Moreover the localization of spillovers is shown by patent citation studies which document that there are also technology transfers from local sources to foreign subsidiaries (Almeida, 1996; Branstetter, 2000; Frost, 1998) and by studies that have found that firms may invest abroad with the aim to absorb technological knowledge (Neven and Siotis, 1996; Frost,1998).

These studies indicate that knowledge flows between the MNE's subsidiary and the local producers take place in both directions. Cassiman and Veugelers (2002, 2004) show that foreign subsidiaries are more likely to be acquiring local know-how than to be transferring know-how to the local economy. This asymmetry in the intensity of external knowledge flows between foreign subsidiaries and local producers is confirmed by Singh (2007).

This evidence suggests that technological spillovers can be modelled as dependent on the mode chosen by the firm to serve the foreign market, since a closer location increases the degree of knowledge transmission. Thus we need to introduce a "proximity" effect into the model (that is, we can assume that multinational companies -MNEs- and exporters operate with different degrees of technological spillovers) and an asymmetry between the incoming and the outgoing spillover for an MNE.

The geographical dimension of spillovers have been accounted for only by a few theoretical models, which however consider R&D as exogenous and thus have a short run nature. In fact the papers by Ethier and Markusen (1996), Fosfuri and Motta (1999) and Siotis (1999) examine how localized spillovers may affect the firm's decisions on how to serve a foreign market. Furthermore in these models only one firm is allowed to expand abroad. The only analytical study addressing the impact of spillovers localisation within a model allowing for endogenous R&D is Petit, Sanna-Randaccio and Sestini (2005)[1]. Such study presents a dynamic model which highlights the differences between short run and long run effects. However, the complexity of the model does not allow for analytical results and thus the findings are only based on numerical simulations.

We build here a static model, endogenizing both the level of R&D investment and the firms' mode of foreign expansion, which allows us to obtain analytical results that more fully highlight the economic mechanisms through which asymmetric spillovers influence firm's internationalisation and innovation strategies. We start with a simplified version of the model where market structure is exogenous, focusing on the effects of asymmetric spillovers on the equilibrium R&D investment in oligopolistic markets. Then we present an extended version of the model where *both* the firms' mode of foreign expansion and R&D level are endogenously determined in the presence of localized spillovers. We consider only the case of low spillovers as this appears to be the most relevant empirical case [2].

[1] See also Piga and Poyago-Theotoky (2005), who present an Hotelling type model where firms competing in prices choose their R&D effort and the extent of location/product differentiation.

[2] For instance, on the basis of survey data, Gupta and Govindarajan (2000) find a surprisingly low intensity of knowledge transfers <u>within</u> the MNE network (i.e. considering two-way knowledge transfers between parent and subsidiary and two-way knowledge flows among sister subsidiaries). We should expect the intensity of inter-firm spillovers -as we consider- to be lower than that of intra-firm spillovers -as examined by Gupta and Govindarajan-. A similar conclusion can be reached by estimating an 'innovation function' with inputs given by R&D activity carried out in a given region and R&D performed in other regions at different and increasing geographical distances, as in Bottazzi and Peri (2003). The econometric

Along the lines of Petit and Sanna-Randaccio (2000)[3], but allowing for asymmetric spillovers, we set up a two-country imperfect competition model with two firms -one from each country- producing a homogeneous good. In particular we specifically investigate process-enhancing or cost reducing R&D investment. The extended model is structured as a three stage game in which each firm must take three different type of decisions: (i) the mode of foreign expansion - export or FDI - (ii) how much to invest in R&D, (iii) how much to sell in each market. The equilibrium market structure is therefore endogenously determined as the solution of the three stage game.

The paper is organised as follows. Section 2 presents the first simplified version of the model. Section 3 introduces the extended model examining the effects of localized technological spillovers on R&D activities and on the optimal internationalization strategies of firms. Section 4 presents the main conclusions.

2 The simplified model: increasing incoming spillovers via know-how management

We build here the simplest model that may capture the effects of asymmetric knowledge flows. There are two firms ($i \in \{1, 2\}$), which produce a homogeneous good in two identical countries (country I and II) and compete in quantities *à la Cournot*. Learning resulting from investment in R&D characterizes the production process, implying that marginal and unit costs decrease as investment in R&D increases. That is, we consider process innovations that result in reductions in production costs.

Notice that in our set-up the rivalry as to the innovation activity is of a non-tournament kind. This implies that there exist many different research paths that firms can follow,

analysis considers the coefficients of the employment in R&D in other regions as a measure of the intensity of cross- regional spillovers. This comes out to be significant, decaying with distance and markedly lower than 0.5.

[3]Petit and Sanna-Randaccio (2000) considers only the case of symmetric spillovers, and thus cannot address issues such as increased efficiency in know-how management or spillovers localisation.

each leading to an equivalent amount of R&D expenditure and generating thus an equivalent reduction in production costs. Hence rivals cannot prevent any firm from obtaining equivalent improvements through spending equivalent amounts of resources in R&D (De Bondt, 1996).

Let I_i be the investment in research undertaken by firm i (own R&D) and let $m_i(I_i)$ denote firm i's marginal (unit variable) cost ($i = 1, 2$). The function $m_i(I_i)$ represents the (negative) relationship between firm i's marginal cost and its level of R&D investment given by I_i. In addition we allow for the possibility of imperfect appropriability (i.e. technological spillovers between the firms), introducing a spillover parameter $\alpha_i \in [0, 1],\ i = 1, 2$. In our framework this parameter, though exogenously given, is meant to reflect the notion of different abilities by the firms to manage external information flows.

Given this assumption on spillovers, the magnitude of firm i's cost reduction is determined by its own R&D and by a fraction α_i of the other firm's investment. In our set-up then the parameter α_i is an *incoming* spillover. More specifically, denoting with $\underline{I} = (I_1, I_2)$

$$m_i\ (\underline{I}) = A_i - \theta(I_i + \alpha_i I_j) \qquad i, j = 1, 2,\ i \neq j \tag{1}$$

The parameter A_i in (1) acts as a reduction in marginal cost and can be considered as the initial marginal cost of firm i, i.e. the cost that would prevail with no investment in R&D[4]. The parameter θ, with $\theta \geq 0$, determines the rate at which m_i declines with an increase in the R&D level. It represents the productivity of the firm's research effort. The expression $(I_i + \alpha_i I_j)$ represents firm's i total knowledge, also called effective R&D.

The inverse demand function for each market is linear and defined as

[4] For a similar specification see D'Aspremont and Jacquemin (1988) and Wang and Blomstrom (1992), who assume $\theta = 1$. The specification of cost-reducing innovation can easily be extended to the case of product innovation, where R&D investments shift the intercept of the demand curve upwards as in De Bondt et al. (1988) and Veugelers and Vanden Houte (1990).

$$p_I = a - b\,(q_{1,I} + q_{2,I}) \qquad p_{II} = a - b\,(q_{1,II} + q_{2,II}) \tag{2}$$

where p_I and p_{II} denote prices in country I and II respectively, and $q_{i,k}$ represents the sales of firm i in country k ($i = 1,2, \quad k = I, II$). The parameters a and b are positive constants and $1/b$ measures the size of the market in each country. We assume parameter values which guarantee the non negativity of prices and marginal costs and which ensure the possibility for both firms to be active[5].

At this stage *we assume* that both firms are multinationals (i.e. each firm undertakes a direct investment - FDI - by creating a production subsidiary in the rival's country). This implies that plant specific fixed costs G should be included twice in the objective function of both firms.

Each firm then maximizes profits, given by

$$\begin{aligned}\pi_1^{DD} &= (a - b\,(q_{1,I} + q_{2,I}))\,q_{1,I} + (a - b\,(q_{1,II} + q_{2,II}))\,q_{1,II} \\ &\quad -(A_1 - \theta(I_1 + \alpha_1 I_2))(q_{1,I} + q_{1,II}) - \tfrac{\gamma I_1^2}{2} - F - 2G\end{aligned} \tag{3}$$

$$\begin{aligned}\pi_2^{DD} &= (a - b\,(q_{1,I} + q_{2,I}))\,q_{2,I} + (a - b\,(q_{1,II} + q_{2,II}))\,q_{2,II} \\ &\quad -(A_2 - \theta(\alpha_2 I_1 + I_2))(q_{2,I} + q_{2,II}) - \tfrac{\gamma I_2^2}{2} - F - 2G\end{aligned} \tag{4}$$

where the superscript DD stands for MNE-duopoly.

Notice that in (3) and (4) we modelled the cost of investment in R&D as $\gamma I^2/2$, with $\gamma > 0$. This simple quadratic investment cost function guarantees decreasing returns to R&D expenditure (see e.g. Cheng, 1984) [6].

We want to allow for the possibility of imperfect appropriability in the form of (asymmetric) technological spillovers between the firms. Obviously the case of no spillovers

[5] In particular, we assume that

$I_i + \alpha_i I_j \leq \dfrac{A_i}{\theta} \quad i,j = 1,2 \quad i \neq j, \qquad q_{i,k} > 0 \quad i = 1,2 \quad k = I, II, \quad q_{1,I} \leq \dfrac{a - bq_{2,I}}{b}, \quad q_{1,II} \leq \dfrac{a - bq_{2,II}}{b}, \quad a > A_i > 0 \quad i = 1,2.$

[6] This assumption is justified by d'Aspremont and Jacquemin (1988) by noting that the technological possibilities linking R&D inputs to innovative output do not display any economies of scale.

($\alpha_i = 0$) may only arise in a situation of strong intellectual protection. More frequently, however, involuntary information leaks occur as a result of reverse engineering, industrial espionage or by hiring away employees of an innovative firm. The cases of partial to full spillovers can be modelled by setting $0 < \alpha_i \leq 1$. Notice that in this paper we consider only the case of $\alpha_i < 0.5$, as it represents the empirically most relevant scenario. Moreover, we recall that the asymmetry here is the outcome of different abilities by firms to absorb or assimilate intra-industry spillovers [7].

Equilibrium will be determined by solving a two stage Cournot duopoly game. In the first stage firms decide how much to invest in R&D, knowing that these decisions are irreversible. In the second stage each firm optimally chooses the amount of sales in both countries (and therefore of output). The subgame perfect equilibrium output and investment levels are obtained using backwards induction. For the sake of simplicity we take into account the simplest case where both firms are identical but for different know-how management capabilities. This equals to saying that no firm has an initial cost advantage over the other, i.e. $A_1 = A_2$.

2.1 Strategic investments with asymmetric spillovers

We begin by solving the second stage of the game, at which each firm i chooses the level of its sales at home and abroad, and thus its own level of output, maximizing its objective function as in (3) and (4) under the Cournot assumption. We thus obtain

$$q_{1,I} = q_{1,II} = \frac{a - A + \theta(2 - \alpha_2)I_1 + \theta\,(2\,\alpha_1 - 1)I_2}{3\,b} \tag{5}$$

$$q_{2,II} = q_{2,I} = \frac{a - A + \theta(2 - \alpha_1)I_2 + \theta(2\,\alpha_2 - 1)I_1}{3\,b} \tag{6}$$

[7] As explained in De Bondt and Henriques (1995), some firms - but not necessarily those with lower initial costs - may be more efficient in absorbing and managing the rivals' innovative ideas. This occurs not because they themselves are more able to be innovative but rather because they are better in learning from the others.

Notice that for each firm sales increase with its own level of R&D. As a matter of fact, by increasing its own innovative effort the firm succeeds in decreasing unit costs and increasing consequently its competitiveness in the product market. This occurs for any value of the outgoing spillover, though the positive effect is weakened as the outgoing spillover becomes high.

On the other hand, the value of the incoming spillover is crucial in order to establish the sign of the effect on sales of each firm stemming from the investment in R&D of the rival. In particular, if the incoming spillover for firm i is given by $\alpha_i < 0.5$ this effect is negative, whilst it is positive for $\alpha_i > 0.5$. This may be explained by noting that, from the standpoint of firm i, when the spillover parameter is rather small ($\alpha_i < 0.5$), the negative effect on firm' i sales stemming from an increase in the rival's competitiveness (due to R&D investment) prevails over the positive effect due to the portion of knowledge absorbed from firm j's innovative activities. The opposite holds, obviously, when the spillover parameter is greater than 0.5 and the positive effects prevails over the negative one.

In order to obtain Nash equilibrium strategies for I_1 and I_2 we maximize objective functions as given by (3) and (4) with respect to R&D investments , having substituted for quantities $q_{1,I}$, $q_{1,II}$, $q_{2,I}$ and $q_{2,II}$ as stated here above.

We thus obtain best response functions for investment in R&D:

$$I_i = \frac{4\,(a-A)\,(2-\alpha_j)\,\theta}{9\,b\,\gamma - 4\,(2-\alpha_j)^2\,\theta^2} + \frac{4\,(2-\alpha_j)\,(2\,\alpha_i - 1)\,\theta^2}{9\,b\,\gamma - 4\,(2-\alpha_j)^2\,\theta^2} I_j \tag{7}$$

$i, j = 1, 2 \ \ (i \neq j)$.

Notice that the second order condition, guaranteeing the local concavity of the objective function is given by $9b\gamma - 4(2-\alpha_i)^2\theta^2 > 0, \quad i, j = 1, 2, \ i \neq j$. Moreover, it is easy to establish that the slope of firm's i reaction function is negative (positive) if $\alpha_i < 0.5$ ($\alpha_i > 0.5$), independently from the value assumed by α_j [8]. From Eqs. (7) we get the equilibrium values of R&D levels

[8] Moreover, by evaluating the sign of the condition: $\frac{\partial^2 \Pi_i}{\partial I_i \partial I_j} = \frac{-4\theta^2(2\alpha_j - 1)(\alpha_i - 2)}{9b} \qquad i, j = 1, 2,$ we conclude that R&D investments are strategic substitutes (complements)if $\alpha_i < (>) 0.5$ and $\alpha_j < (>) 0.5$.

$$\hat{I}_i^{DD} = \frac{4\,(a-A)\,(2-\alpha_j)[3\,b\,\gamma - 4\theta^2(2-\alpha_i)(1-\alpha_i)]\,\theta}{\Psi} \qquad i=1,2 \tag{8}$$

where $\Psi = 27\,b^2\,\gamma^2 - 12\,b\,\gamma\,\theta^2\,[(2-\alpha_i)^2 + (2-\alpha_j)^2] + 16\,\theta^4\,(2-\alpha_i)\,(2-\alpha_j)\,(1-\alpha_i\alpha_j)$. Due to stability conditions it is possible to establish that $\Psi > 0$.

Equilibrium solutions for output and price are reported in Appendix A.

Our aim is to focus on the consequences of asymmetric spillovers, that is $\alpha_i \neq \alpha_j$. The parameter α_i is viewed here as the result of a firm-specific absorption factor, due to different know-how management capabilities. That is, one of the two firms is absorbing more knowledge from the rival (i.e. the intensity of its *incoming* spillover is higher, which implies that the intensity of its *outgoing* spillover is lower, as compared to the other firm).

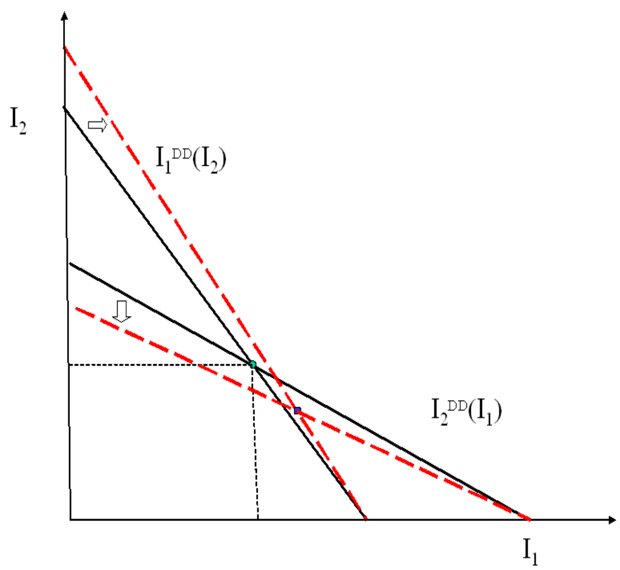

Figure 1: The effect of a rise in α_1 on R&D equilibria.

The effect of a rise in incoming spillover intensity on the firm's innovative performance is illustrated in Figure 1, where the R&D reaction functions of the two firms are represented. We are mainly concerned on whether a rise in absorptive capacity drives up the incentive to invest in own R&D. We will consider the case of a rise in α_1 due to an increased efficiency in know-how management, while α_2 does not change. The model shows that firm 1 (2) reaction function shifts upwards (downwards) rotating around its horizontal intercept (see proof). It follows that if the firm enjoys a higher ability to source external knowledge is also stimulated to increases its own R&D, while the reverse is the case for the other firm. In other words, the asymmetry generated by the rise in α_1 enhances firm's 1 profitability and thus the stimulus to innovate.

We are able to state:

Proposition 1. *An asymmetry due to an increase in incoming spillover intensity - ceteris paribus - leads to higher own R&D.*

Proof of Proposition 1. Let us rewrite best response functions as in (8) in a simplified form:

$$I_1^{DD} = \frac{M_1}{J_1} + \frac{N_1}{J_1} I_2^{DD} \tag{9}$$

and

$$I_2^{DD} = \frac{M_2}{J_2} + \frac{N_2}{J_2} I_1^{DD} \tag{10}$$

where $M_i = 4\,\theta(2-\alpha_j)(a-A)$,

$J_i = 9\gamma\, b - 4\theta^2(2-\alpha_j)^2$,

$N_i = 4\,\theta^2(2-\alpha_j)(2\alpha_i - 1) \quad i,j = 1,2, \;\; i \neq j.$

Equilibrium investments are then given by:

$$\hat{I}_i^{DD} = \frac{M_i J_j + N_i M_j}{J_i J_j - N_i N_j} \;\; i,j = 1,2, \;\; i \neq j \tag{11}$$

Notice that focusing on strategic substitutes R&D investments implies that $N_i < 0$.

Examining the effect of an increase in the incoming spillover (i.e. α_1) on own R&D equilibrium investment of firm 1, it is easy to find that, as α_1 gets higher, firm 1's reaction function shifts upwards, pivoting around its horizontal intercept as its slope decreases ($\frac{\partial(|J_1/N_1|}{\partial \alpha_1} = \frac{8\theta^2(2-\alpha_2)J_1}{N_1^2} > 0$, because of SOC), and the vertical intercept increases ($\frac{\partial(-M_1/N_1)}{\partial \alpha_1} = \frac{(a-A)}{\theta(1-2\alpha_1)} > 0$). On the other hand, firm 2's reaction function shifts downwards, pivoting around its horizontal intercept ($\frac{\partial(|M_2/N_2|}{\partial\alpha_1} < 0$ along with $\frac{\partial(|N_2/J_2|}{\partial\alpha_1} < 0$). □

It is also possible to show that:

Proposition 2. *A rise in outgoing spillover intensity - ceteris paribus - results in lower own R&D.*

Proof of Proposition 2. Straightforward, as this equals to examining how firm 2 reacts to an increase in α_1.

□

To summarize, the equilibrium level of own R&D investment chosen by firm 1 raises after an increase in the level of the incoming spillover intensity, whilst higher outgoing spillovers intensity depresses the incentive to invest in R&D, due to the fear of dissipation of its own technological knowledge.

3 The extended model: increasing incoming spillovers by locating abroad

In this section we explore another source of asymmetry in the involuntary transmission of technological knowledge. Firms are supposed henceforth to be identical in all respects. However technological spillovers still differ in intensity since they depend on the mode chosen by firms to serve the foreign market.

Now firms face <u>three</u> types of decisions: how to expand abroad, how much to invest in R&D, and finally how much to sell in each country. At the first stage of the game the duopolists choose the mode of foreign expansion, with a strategy space made of two possible strategies: export (EXP), i.e. producing in the home country and exporting abroad, and foreign direct investment (FDI), that is producing in both countries, thus becoming a multinational. We also assume that the choice of exporting implies additional unit (and marginal) transport costs denoted by s, whilst, as explained in section 2, the FDI choice brings about additional plant specific fixed costs G.

Beside the case of a *MNE duopoly*, where the objective functions are as specified in (3) and (4), we introduce now two further possible (different) market configurations, with their respective objective functions. An *exporting duopoly* arises when both firms have only one plant in a country and export to the other country. Profits are then given by:

$$\begin{aligned} \pi_1^{EE} &= (a - b\ (q_{1,I} + q_{2,I}))\ q_{1,I} + (a - b\ (q_{1,II} + q_{2,II}))\ q_{1,II} \\ &-(A_1 - \theta(I_1 + \alpha_1 I_2))\ q_{1,I} - (A_1 - \theta(I_1 + \alpha_1 I_2) + s)\ q_{1,II} - \tfrac{\gamma I_1^2}{2} - F - G \end{aligned} \tag{12}$$

$$\begin{aligned} \pi_2^{EE} &= (a - b\ (q_{1,I} + q_{2,I}))\ q_{2,I} + (a - b\ (q_{1,II} + q_{2,II}))\ q_{2,II} \\ &-(A_2 - \theta(\alpha_2 I_1 + I_2))\ q_{2,II} - (A_2 - \theta(\alpha_2 I_1 + I_2) + s)\ q_{2,I} - \tfrac{\gamma I_2^2}{2} - F - G \end{aligned} \tag{13}$$

where the superscript EE stands for exporting duopoly.

Lastly, we allow for the case of a *mixed duopoly*, with a MNE and a exporting firm. In this scenario, one firm serves the other country by creating a new plant and the rival firm by exporting. Assuming firm 1 to be the exporting firm and firm 2 the MNE (i.e. the ED-duopoly[9]), profits are given by:

$$\begin{aligned} \pi_1^{ED} &= (a - b\ (q_{1,I} + q_{2,I}))\ q_{1,I} + (a - b\ (q_{1,II} + q_{2,II}))\ q_{1,II} \\ &-(A_1 - \theta(I_1 + \alpha_1 I_2))\ q_{1,I} - (A_1 - \theta(I_1 + \alpha_1 I_2) + s)\ q_{1,II} - \tfrac{\gamma I_1^2}{2} - F - G \end{aligned} \tag{14}$$

$$\begin{aligned} \pi_2^{ED} &= (a - b\ (q_{1,I} + q_{2,I}))\ q_{2,I} + (a - b\ (q_{1,II} + q_{2,II}))\ q_{2,II} \\ &-(A_2 - \theta(\alpha_2 I_1 + I_2))(q_{2,I} + q_{2,II}) - \tfrac{\gamma I_2^2}{2} - F - 2G \end{aligned} \tag{15}$$

We leave out the analysis of the MNE duopoly, having already determined best response functions (see equation (7)), equilibrium investments in R&D (eq. (8)) and equilibrium quantities (eq. (31)) and prices (eq. (32)).

[9]Due to the symmetric nature of the model the DE case will not be examined.

Exporting duopoly

Under this market configuration, likewise as in Section 2, we first obtain the values of the sales variables as functions of I_1 and I_2 and substitute them into the profit functions. We then get the reaction functions for investment in R&D:

$$I_i = \frac{4\,(a-A)\,(2-\alpha_j)\,\theta}{9\,b\,\gamma - 4\,(2-\alpha_j)^2\,\theta^2} - \frac{2\,s(2-\alpha_j)\,\theta}{9\,b\,\gamma - 4\,(2-\alpha_j)^2\,\theta^2} + \frac{4\,(2-\alpha_j)\,(2\,\alpha_i - 1)\,\theta^2}{9\,b\,\gamma - 4\,(2-\alpha_j)^2\,\theta^2} I_j \qquad (16)$$

$i, j = 1, 2 \;\; (i \neq j)$. Employing a more compact notation, we can rewrite equations (16) as:

$$I_1^{EE} = \frac{M_1}{J_1} - \frac{T_1}{J_1} + \frac{N_1}{J_1} I_2^{EE} \qquad (17)$$

and

$$I_2^{EE} = \frac{M_2}{J_2} - \frac{T_2}{J_2} + \frac{N_2}{J_2} I_1^{EE} \qquad (18)$$

where M_i, J_i, N_i are as defined above (see page 11), and $T_i = 2\; s(2-\alpha_j)\theta$ $i, j = 1, 2, \;\; i \neq j$.

Hence equilibrium R&D investments are given by:

$$\hat{I}_i^{EE} = \frac{2\theta(2-\alpha_j)[3b\gamma - 4\theta^2(2-\alpha_i)(1-\alpha_i)][2(a-A)-s]}{\Psi} \qquad i = 1, 2 \qquad (19)$$

where $\Psi = 27\; b^2\; \gamma^2 - 12\; b\; \gamma\; \theta^2\; [(2-\alpha_i)^2 + (2-\alpha_j)^2] + 16\; \theta^4\; (2-\alpha_i)\; (2-\alpha_j)\; (1-\alpha_i\alpha_j)$.

Employing a more compact notation we get

$$\hat{I}_i^{EE} = \frac{M_i J_j + N_i M_j}{J_i J_j - N_i N_j} - \frac{T_i J_j + N_i T_j}{J_i J_j - N_i N_j} \qquad i = 1, 2 \qquad (20)$$

Notice that a positive equilibrium exists for $\hat{I}_i^{EE}$ iff $[3b\gamma - 4\theta^2(2-\alpha_i)(1-\alpha_i)] > 0$, which is the same condition ensuring positivity of equilibrium R&D investments and quantities in the MNE duopoly examined in the previous section [10].

Mixed duopoly

We shall consider now the case in which one firm expands abroad via FDI while the other does so via exports. As already mentioned, we assume that firm 1 exports the output produced in its home country while firm 2 becomes a MNE.

Again, we solve the game backwards. In the third stage each firm chooses its own levels of sales at home and abroad, maximizing its profit function under the Cournot assumption. We thus obtain the values of the sales variables as functions of I_1 and I_2. Substituting them into the profit functions and maximizing with respect to I_1 and I_2 we get the best response functions for investment in R&D, i.e.

$$I_1 = \frac{4\,\theta(a-A)\,(2-\alpha_2)}{9\,b\,\gamma - 4\,(2-\alpha_2)^2\,\theta^2} - \frac{4\,s\,\theta(2-\alpha_2)}{9\,b\,\gamma - 4\,(2-\alpha_2)^2\,\theta^2} + \frac{4\,(2-\alpha_2)\,(2\,\alpha_1-1)\,\theta^2}{9\,b\,\gamma - 4\,(2-\alpha_2)^2\,\theta^2} I_2 \tag{21}$$

and

$$I_2 = \frac{4\,\theta(a-A)\,(2-\alpha_1)}{9\,b\,\gamma - 4\,(2-\alpha_1)^2\,\theta^2} + \frac{2s\,\theta(2-\alpha_1)}{9\,b\,\gamma - 4\,(2-\alpha_1)^2\,\theta^2} + \frac{4\,(2-\alpha_1)\,(2\,\alpha_2-1)\,\theta^2}{9\,b\,\gamma - 4\,(2-\alpha_1)^2\,\theta^2} I_1 \tag{22}$$

or, employing a more compact notation:

$$I_1^{ED} = \frac{M_1}{J_1} - \frac{V_1}{J_1} + \frac{N_1}{J_1} I_2^{ED} \tag{23}$$

and

$$I_2^{ED} = \frac{M_2}{J_2} - \frac{T_2}{J_2} + \frac{N_2}{J_2} I_1^{ED} \tag{24}$$

[10] In the case of exporting firms, given the presence of transport costs s, the condition for a firm to be active becomes $a - A - s > 0$. It follows that $2\ (a-A) > s$ and, therefore, the numerator of Eq.(19) is positive.

where M_i, J_i, N_i, T_i are as already defined and $V_i = (4\, s(2-\alpha_j)\,\theta)$, $i, j = 1, 2$, $i \neq j$.

Under this market configuration, Nash equilibrium values for investment in R&D are given by:

$$\hat{I}_1^{ED} = \frac{2\,\theta(2-\alpha_2)[3\,b\,\gamma - 4\theta^2(2-\alpha_1)(1-\alpha_1)][2(a-A)-s]}{\Psi} - \frac{2\,s(3\,b\,\gamma - 4\,\theta^2\,\alpha_1(2-\alpha_1)}{\Psi} \tag{25}$$

$$\hat{I}_2^{ED} = \frac{4\,(a-A)\,(2-\alpha_1)[3\,b\,\gamma - 4\theta^2(2-\alpha_2)(1-\alpha_2)]\,\theta}{\Psi} + \frac{2\,s(2-\alpha_1)\theta\;3b\,\gamma - 4\theta^2\,\alpha_2(2-\alpha_2)}{\Psi} \tag{26}$$

or, employing a more compact notation:

$$\hat{I}_1^{ED} = \frac{M_1 J_2 + N_1 M_2}{J_1 J_2 - N_1 N_2} - \frac{V_1 J_2 + N_1 T_2}{J_1 J_2 - N_1 N_2} \tag{27}$$

and

$$\hat{I}_2^{ED} = \frac{M_2 J_1 + N_2 M_1}{J_1 J_2 - N_1 N_2} - \frac{T_2 J_1 - N_2 V_1}{J_1 J_2 - N_1 N_2} \tag{28}$$

Since we want to focus on role of asymmetric knowledge flows in encouraging (or discouraging) innovative efforts, we proceed now with some relevant assumptions regarding the geographical dimension of know-how transfers, which can be reasonably regarded as a source of asymmetry.

3.1 Assumptions on spillovers localization

We assume henceforth that the effects of geographical distance on the transmission of information between the firms should be taken into account. As a matter of fact, in assessing which agent benefits more from the rivals' knowledge stock, a notion of distance (or proximity) between the technology receiver and the generator has been shown to be relevant in many empirical studies (see, among others, Singh, 2004; Almeida, 1996, Neven and Siotis, 1996; Frost, 1998).

Aiming at introducing this notion as a source of asymmetry in knowledge flows we make the following assumptions on the spillover parameter [11].

A1

The transfer of know-how between two exporters is lower than between two MNEs, i.e.:

$\alpha_{ij}^{EE} < \alpha_{ij}^{DD}, \quad i = 1, 2, \quad j = I, II,$

where α_{ij} is the portion of the knowledge produced by other firm(s) which is absorbed by firm i in country j, representing thus an incoming spillover parameter for firm i in country j. Recalling that in the ED case firm 1 is the exporter and firm 2 the MNE, the following assumption also holds:

A2

$\alpha_{1I}^{ED} < \alpha_{2I}^{ED}$.

In country I, the degree of transmission of technology from the local firm (firm 1) to the MNE (firm 2) (α_{2I}^{ED}) is stronger than the degree of transmission from the MNE to the local firm (α_{1I}^{ED}). This is due to the fact that firm 1 (the local firm) cannot fully exploit some of the know-how transfer mechanisms (like personnel mobility or industrial espionage), since the bulk of research activities undertaken by firm 2 is located in its home country. Moreover, subsidiaries may try to prevent know-how from leaking out (for instance reducing the mobility of personnel by paying higher wages, or applying other strategies to minimize spillovers). On the other hand, the MNE (firm 2) can take advantage of all the knowledge transfer mechanisms, since it produces in country I where the local firm (firm 1) has its main center of research activity. Empirical research gives support to

[11] For a better understanding of our assumptions we employ at this stage an index referring to each country and an index referring to each firm.

this hypothesis, as shown in Veugelers and Cassiman (2004) and Singh (2006).

A3

When both firms are multinationals (the DD case), they can take advantage of all the information transfer mechanisms since both firms have a plant in the rival's home country. Therefore, the transfer of know-how between two MNEs is the same as for the MNE in the mixed oligopoly (ED).

$\alpha_{2I}^{ED} = \alpha_{2I}^{DD} = \alpha_{1II}^{DD}$.

A4

We also hypothesize that there is no cost of technology transfer from the parent firm to the subsidiary, and vice versa. Therefore, the fraction of knowledge that firm i receives in country I is the same as the fraction it receives in country II. It thus follows that

$\alpha_{2I}^{ED} = \alpha_{2II}^{ED}$.
$\alpha_{1I}^{DD} = \alpha_{1II}^{DD}$
$\alpha_{2I}^{DD} = \alpha_{2II}^{DD}$.

This assumption makes it possible to eliminate the country indexes [12].

We can therefore simplify the relationships between the spillover parameters as follows:

$\alpha_i^{EE} < \alpha_i^{DD}, \quad i = 1, 2.$
$\alpha_1^{ED} < \alpha_2^{ED}$
$\alpha_2^{ED} = \alpha_1^{DD} = \alpha_2^{DD}$

As to the relationship between α_1^{EE} and α_1^{ED}, the following assumptions can be made: (i) the fraction of technological information received by the exporting firm 1 in the case of two exporters (α_1^{EE}) is the same as that received by the exporting firm 1 when firm 2 is a MNE (α_1^{ED}), that is $\alpha_1^{EE} = \alpha_1^{ED}$, or (ii) since in the ED case the subsidiary of firm 2 is producing in country I, some more information leaks from firm 2 towards firm 1 may

[12] Notice that eliminating the country indexes is straightforward for exporting firms as they have only one plant located in their home country.

occur if compared with the EE case, that is $\alpha_1^{EE} < \alpha_1^{ED}$. Therefore, it seems appropriate to assume:

$\alpha_1^{EE} \leq \alpha_1^{ED}$

Therefore, taking into account all the above inequalities, we can write:

$\alpha_i^{EE} \leq \alpha_1^{ED} < \alpha_2^{ED} = \alpha_i^{DD}$.

Hence, even if the spillover parameters are not explicit functions of location, as in Duranton (2000), they are related to location (in our case, to the mode of foreign expansion) by the above defined constraints that α_i and α_j must satisfy.

We also point out that, even if in the export-export case the distance between the two firms is the highest, this does not necessarily mean that there is no transmission of knowledge. The transmission can always take place through some of the usual channels of know-how transfer, i.e. reverse engineering (from imported goods), and also from international personnel mobility, journals and conferences.

3.2 Spillovers localization and the incentive to innovate

In this section our assumptions on spillovers localization will be inserted into the model, mainly investigating the impact that asymmetries in the degree of knowledge transmission - due to differences in location- may have on the incentive to innovate under different market configurations.

We carry out firstly a comparison between firms' innovative performance under the DD case and under the EE case. Denoting with α^{DD} the (common) value of the parameter $\alpha_1^{DD} = \alpha_2^{DD}$ and with α^{EE} the value of the parameter $\alpha_1^{EE} = \alpha_2^{EE}$, we substitute for α_i and α_j , $i, j = 1, 2,\ i \neq j$ into equations (8) and (19).

We thus obtain:

$$\tilde{I}_1^{DD} = \tilde{I}_2^{DD} = \frac{4\,(a-A)\,(2-\alpha^{DD})\,\theta}{9\,b\,\gamma - 4\,(2-\alpha^{DD})\,(1+\alpha^{DD})\,\theta^2} \tag{29}$$

and

$$\tilde{I}_1^{EE} = \tilde{I}_2^{EE} = \frac{4\ (a-A)(2-\alpha^{EE})\ \theta}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} - \frac{2s\ (2-\alpha^{EE})\ \theta}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} \tag{30}$$

We can thus state the following proposition:

Proposition 3. *In an international duopoly with localized spillovers, whether* $\tilde{I}_i^{DD} \gtreqless \tilde{I}_i^{EE}$ *depends on the relative magnitude of the market expansion effect versus the free-riding effect.*

Proof of Proposition 3. Let us define

$$\begin{aligned} \Delta = \tilde{I}_i^{DD} - \tilde{I}_i^{EE} \quad &= \quad [\frac{4\,(a-A)(2-\alpha^{DD})\theta}{9b\gamma - 4(2-\alpha^{DD})(1+\alpha^{DD})\theta^2} - \frac{4(a-A)(2-\alpha^{EE})\ \theta}{9b\gamma - 4\,(2-\alpha^{EE})(1+\alpha^{EE})\theta^2}] + \\ &+ \quad \frac{2s\ (2-\alpha^{EE})\ \theta}{9b\gamma - 4(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} \end{aligned}$$

Denoting with Ω^K the ratio $\frac{4\,(a-A)(2-\alpha^K)\theta}{9b\gamma-4(2-\alpha^K)(1+\alpha^K)\theta^2}$, with $K \in \{DD, EE\}$, we have that $\Delta = [\Omega^{DD} - \Omega^{EE}] + \frac{2s\ (2-\alpha^{EE})\ \theta}{9b\gamma-4(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2}$. Reminding that our assumptions on spillovers localization imply $\alpha^{EE} < \alpha^{DD}$, then the first term in Δ - the term between square brackets - representing the free-riding effect, is non positive, since $\frac{\partial\Omega^K}{\partial\alpha} = \frac{4\theta(a-A)(4\theta^2(2-\alpha)^2-9b\gamma)}{[9b\gamma-4\theta^2(2-\alpha)(1+\alpha)]^2} \leq 0$, because of SOC. The second term, which can be seen as the market enlargement effect of FDI, is obviously positive.

□

This proposition sheds light on two contrasting forces affecting the innovative performance of firms (MNEs versus exporters) in an international duopoly with localized spillovers. In particular, the free riding - or disincentive- effect stemming from spillovers implies that higher (both incoming and outgoing) spillovers drives down own R&D effort. This is the typical negative effect according to which non-cooperative strategic R&D levels typically decrease with the magnitude of the spillovers, since the presence of leakages tends to limit the appropriability of individual activities. Given our assumptions on geographically bounded spillovers, this effect displays greater negative consequences as proximity increases.

On the other hand, the FDI choice - as compared to export - by eliminating transport costs removes the cost advantage enjoyed by the locally based producer vis-à-vis the foreign one, thus increasing competition in the product market. This results in an increase in the foreign sales of MNEs as compared to exporters. As a matter of fact, the possibility to serve a larger market typically increases the profitability of the research expenditures and therefore may become an incentive for the MNEs to invest more in research than the exporting firms, due to the so-called "market expansion effect".

Again under the hypothesis of spillovers localization, equilibrium values for the sales of each firm at home and abroad and then equilibrium prices are computed (for each market configuration considered). Analytical results along with a comparison between outputs and prices under the EE case and the DD case, respectively, are reported in Appendix B.

We now carry out a comparison in terms of innovative performance between the mixed duopoly and the case of a duopoly made of two exporters. As we are interested in disentangling the effect of an increase in incoming spillovers due to greater proximity to the rival's R&D main labs, we maintain now that $\alpha_i^{EE} = \alpha_1^{ED} < \alpha_2^{ED} = \alpha_i^{DD}$.

Moving from the graphical analysis of the best response functions in the EE case (see Eqs (17) and (18)) and in the ED case (Eqs. (23) and (24)), Figure 2 shows that the reaction curve of firm 2 in the ED duopoly is characterized by both a higher vertical intercept and (in absolute value) a lower slope. The first effect (on the intercept) captures the benefit for firm 2 due to transport costs elimination, when moving from export to FDI. The slope effect instead is due to firm's 2 increased ability to source local knowledge due to a rise in α_2. At the same time, the intercept of firm's 1 reaction curve in the ED case shifts downwards (as firm 1 is not any more protected in the home market by transport costs) and the slope (in absolute value) increases because of higher outgoing spillovers.

We are then able to state that:

Proposition 4. *When localized spillovers lead to an increase in the incoming spillover of the investor, one-way FDI results in a rise in the MNE own R&D and in a decrease in the local firm own R&D.*

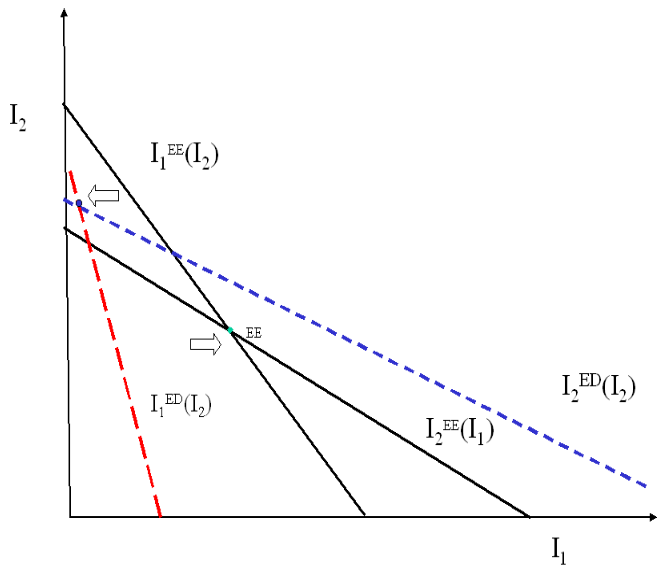

Figure 2: A comparison of R&D investments in the EE and in the ED case

Proof of Proposition 4. Examining the best response function of firm 1 in the EE case (Eq. 17) and in the ED case (Eq. 23) respectively, the vertical intercept in the latter market structure is lower than the vertical intercept in the former case, being $-\frac{M_1}{N_1}+\frac{T_1}{N_1} > -\frac{M_1}{N_1}+\frac{V_1}{N_1}$, as both $\frac{T_1}{N_1}$ and $\frac{V_1}{N_1}$ are negative. As to the slope, the expression $\frac{J_1}{N_1}$ differs in the EE case and in the ED case, since $\alpha_2^{EE} < \alpha_2^{ED}$. We easily find that $\frac{\partial(|J_1/N_1|)}{\partial\alpha_2} > 0$. Then, considering the best response function of firm 2 under both market structures, we obtain that the vertical intercept in the ED case is higher than the vertical intercept in the EE case, having assumed that $\alpha_1^{EE} = \alpha_1^{ED}$. Likewise as previously seen, the slopes differ, with $\frac{\partial(|N_2/J_2|)}{\partial\alpha_2} < 0$. As depicted in Figure 2, it follows that $\tilde{I}_2^{ED} > \tilde{I}_1^{EE} = \tilde{I}_2^{EE} > \tilde{I}_1^{ED}$. $\square$

A comparison between the ED and the DD case gave rise to ambiguous results, because of the presence of two contrasting forces of opposite sign - the market enlargement effect versus the traditional negative spillover effect. Therefore the ranking of R&D investment equilibria strongly depends on the relative magnitude of these effects, likewise in the comparison between equilibrium R&D investments in the DD and in the EE case (see Proposition 3).

We investigate finally the consequences of (increasing) spillovers localization within a market structure -the *mixed duopoly* or *ED* case- where the degree of asymmetry may play a crucial role (as $\alpha_1^{ED} < \alpha_2^{ED}$). In particular we want to ascertain whether or not deepening the degree of localization could give rise to different effects on the firms' innovative performance.

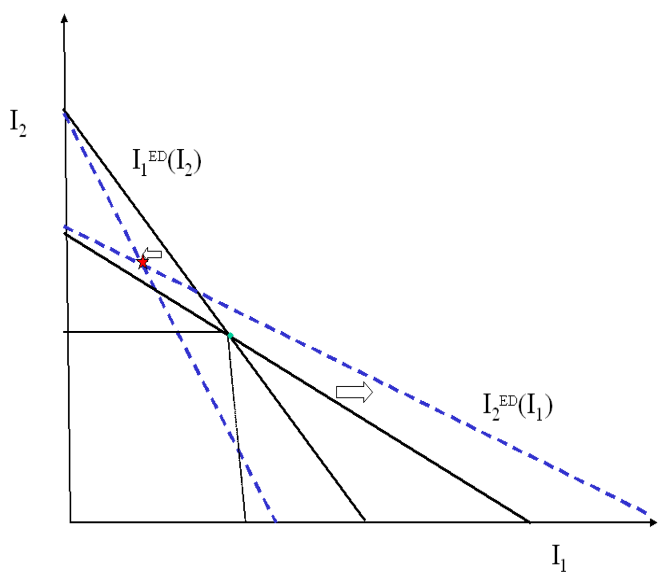

Figure 3: The effect of the degree of spillovers localization on R&D equilibria: ED case

Looking at best response functions as in Eqs. (23) and (24), we examine how an increase in the degree of localization affects R&D equilibrium investment of firms, given our assumptions on the mechanisms of knowledge transmission. In our model this amounts to analyzing the effects of an increase in α_2^{ED}, *ceteris paribus.*

As Figure 3 depicts, the outcome of these changes is that the equilibrium R&D investment by the MNE - firm 2 - is prompted after an increase in the degree of spillovers localization, whilst the investment of the exporting firm is hampered. This may be explained as the result of the asymmetry favouring the multinational firm, due to greater possibilities to source the rival's knowledge through FDI.

We can thus state that:

Proposition 5. *In a mixed duopoly, a rise in the degree of spillovers localization, leading to a higher incoming spillover for the MNE, brings about a rise in own R&D of the MNE and to a fall in own R&D of the local firm.*

Proof of Proposition 5. After an increase in α_2^{ED}, firm 1's reaction function shifts downwards, pivoting around its vertical intercept, with an increasing slope (in absolute value). In fact, we have that ($\frac{\partial(|J_1/N_1|)}{\partial\alpha_2} = \frac{32\theta^4(2-\alpha_2)(1-2\alpha_1)+4\theta^2(1-2\alpha_1)J_1}{N_1^2} > 0$, with $J_1 > 0$ because of SOC), and a decreasing horizontal intercept ($\frac{\partial(M_1-V_1)/J_1}{\partial\alpha_2} = \frac{-(A-a-s)(4\theta J_1+32\theta^3(2-\alpha_2)^2}{J_1^2} < 0$). On the other hand, firm 2's reaction function shifts upwards, pivoting around its vertical intercept (as $\frac{\partial(|N_2/J_2|}{\partial\alpha_2} < 0$ and $\frac{\partial(-M_2/N_2|}{\partial\alpha_2} > 0$). □

3.3 The effect of localized spillovers on the equilibrium strategies for foreign expansion

Since our aim is to endogenize the market structure, we shall examine now how the firms will perform their choices on the mode of foreign expansion and how our assumptions on geographically localized spillovers may affect these choices.

In order to analyse firms' international strategy decisions we need to calculate the profits of each firm corresponding to two different strategies, i.e., EXP (exporting) or FDI (direct investment). Then we will single out Nash equilibrium solution(s) of a matrix game between the two firms, where the pay-offs are the profits of each single firm and the strategy space is $S_i = \{EXP, FDI\},\ i = 1,2$. A Nash equilibrium will determine a subgame perfect equilibrium market structure of the game under analysis. Due to the complexity of equilibrium profits we had to resort to numerical analysis. Being equilibrium profits a function of the value of the spillover parameter $\alpha_i,\ i = 1,2$, we assigned to it

Table 1: Values assigned to the spillover parameters α_i and α_j in the simulations. Rows: industry-specific intensity of spillovers. Columns: degree of localization effect.

LOW	$\alpha_i^{EE} = 0.05,\ \alpha_1^{ED} = 0.1,\ \alpha_2^{ED} = \alpha_i^{DD} = 0.2$
MEDIUM	$\alpha_i^{EE} = 0.1,\ \alpha_1^{ED} = 0.2,\ \alpha_2^{ED} = \alpha_2^{DD} = 0.3$
HIGH	$\alpha_i^{EE} = 0.2,\ \alpha_1^{ED} = 0.3,\ \alpha_2^{ED} = \alpha_i^{DD} = 0.4$

different values depending on the mode of foreign expansion chosen by the firms and thus coherently with the assumptions explained in section 3.1. In particular the values of technological spillovers employed in our simulations are as reported in Table 1.

In choosing the numerical values for this table we introduce the hypothesis that industry-specific features influence the amount of knowledge leaks (eg. legal appropriation regime, complexity of know-how affecting the degree of appropriation). In particular we assume that industry-specific features influence the lowest feasible value of the spillover parameter, i.e. $\alpha_i^{EE}, i = 1, 2$. Therefore we consider low, medium, and high intensity of knowledge diffusion industries, according to the value assigned to this parameter, as indicated by the rows of Table 1. Moreover, the degree of the localization effect is allowed to vary, depending on the value assigned to the parameter $\alpha_i^{DD} = \alpha_2^{ED}$, as indicated in the columns in Table 1. This hypothesis is tailored to ascertain whether or not deepening the degree of localization at the intra-industry level (i.e. within the same sector) could give rise to different effects in terms of market structure. This issue is investigated by increasing the value of $\alpha_i^{DD} = \alpha_2^{ED}$.

As to the other parameters, whenever possible they have been chosen on the basis of available empirical results. In the simulations here reported (see Tables 2-4), they have been assigned the following numerical values: $a = 36,\ b = 2,\ A = 5,\ s = 2,\ \gamma = 1,\ \theta = 0.3,\ G = 15,$ and $F = 10$.

A large number of computations have been carried out in order to assess how different factors (such as host market size, plant scale economies, etc.) affect equilibrium outcomes. For lack of space we discuss here only a selection of these computations, which allows

Table 2: A- The effect of localized spillovers on the equilibrium market structure with low spillovers ($G = 15,\ \theta = 0.3,\ \alpha_i^{EE} = 0.05,\ \alpha_1^{ED} = 0.1, \alpha_i^{DD} = \alpha_2^{ED} = 0.2$)

note: * = Nash equilibrium

		firm 2	
		EXP	FDI
firm 1	EXP	76.4, 76.4	68.4, 77.8
	FDI	77.8, 68.4	69.1*, 69.1*

Table 3: B- The effect of localized spillovers on the equilibrium market structure with medium spillovers ($G = 15,\ \theta = 0.3,\ \alpha_i^{EE} = 0.1,\ \alpha_1^{ED} = 0.2, \alpha_i^{DD} = \alpha_2^{ED} = 0.3$)

note: * = Nash equilibrium

		firm 2	
		EXP	FDI
firm 1	EXP	77, 77	69.7, 78.7
	FDI	78.7, 69.7	70.1*, 70.1*

to ascertain how changes in some parameters (in particular the parameters reflecting the degree of spillovers asymmetry) influence the equilibrium market structure.

Comparing the equilibria shown in Tables 2-4 with a scenario with non localized spillovers (see Petit and Sanna-Randaccio, 2000), we have that, all the other parameters being equal, with geographically bounded spillovers a FDI-FDI equilibrium occurs while in the non localized spillovers case we had an Export-Export solution [13]. We argue that, in an environment characterized by asymmetric knowledge flows, there is an additional motivation for choosing the FDI strategy, represented by the possibility to absorb more technological knowledge from the rival firm. MNEs can thus make higher profits in relation to exporters as they may have access to a larger share of the research produced

[13] We recall that in a model with symmetric spillovers, a switch from the Export-Export to the FDI-FDI equilibrium is induced by a change in some parameters, that is by introducing a higher efficiency in research (i.e. a higher θ), or a reduction in the value of the plant specific fixed cost G.

Table 4: C- The effect of localized spillovers on the equilibrium market structure with high spillovers ($G = 15,\ \theta = 0.3,\ \ \alpha_i^{EE} = 0.2,\ \alpha_1^{ED} = 0.3, \alpha_i^{DD} = \alpha_2^{ED} = 0.4$)

note: * = Nash equilibrium

		firm 2	
		EXP	FDI
firm 1	EXP	78.2, 78.2	70.8, 79.4
	FDI	79.4, 70.8	71*, 71*

by the competitor.

Looking again at Tables 2-4, we can observe that increasing the level of knowledge diffusion within the same industry (i.e. moving from low to high spillovers by increasing the value of α_i^{EE}), or increasing the degree of localization (i.e. increasing the value of spillovers from $\alpha_2^{ED} = 0.2$ up to $\alpha_2^{ED} = 0.4$), improves the profits associated with the FDI choice (within a given market structure).

4 Conclusions

In this paper we examine the consequences of relaxing the assumption according to which firms generate and receive technological spillovers to the same extent. We argue that, on the contrary, firms may try to manage these information flows with the aim of maximizing incoming spillovers. First, firms may attempt at increasing the amount of external knowledge by means of a more efficient know-how management. Secondly, knowledge flows may increase due to proximity to rivals' R&D labs if spillovers are localized.

Taking into account these features we found that asymmetries in knowledge flows significantly affect firms' innovative performance. In particular an increase in incoming spillovers intensity, due for instance to a better ability to manage knowledge flows, drives up the incentive to invest in own R&D. This result is in line with the findings of empirical research, indicating the existence of some complementarity between in-house R&D and external know-how.

The relationship between the degree of asymmetry of knowledge flows, on one side, and the firms' innovative performance, on the other side, becomes more complex if one considers an international oligopoly where both the optimal choice on international expansion and investment in R&D are endogenized. Taking into account the effects of geographical proximity on the transmission of know-how between firms may change the results obtained when these effects are ignored.

In particular, if we compare two MNEs (the so-called DD case) with two exporters (the EE case) we find that whether exporters invest more in R&D than MNEs depends on the relative magnitude of two opposite forces. Since proximity implies a higher level of transmission of technological knowledge, the FDI-FDI choice gives rise to a free-riding effect which is stronger than in the Export-Export case. If this effect prevails over the market expansion effect - due to the elimination of transport costs- firms may invest more in R&D when they both are exporters.

However a more clear-cut result emerges if one examines the so-called mixed duopoly (or ED case) where one firm chooses to serve the foreign market by exporting, and the rival becomes a multinational. We find that one-way FDI stimulates the multinational to raise its own R&D, due to both the elimination of transport costs and a greater ability to source. Furthermore the model shows that the equilibrium R&D investment by the MNE raises after an increase in the degree of spillovers localization, whilst the investment of the exporting firm is hampered. This may be explained as a result of the increased advantage for the multinational firm deriving from its greater possibilities to source the rival's knowledge through FDI.

As regards equilibrium market structures, we have shown that, increasing the degree of spillovers localization, a FDI-FDI equilibrium is more likely to occur. The possibility to absorb a higher proportion of the research produced by the competitor when investing in a foreign country appears to be a further incentive for firms to invest abroad. In fact, MNEs can make higher profits in relation to exporters (when compared with the case of non-localized spillovers) since, in a FDI-FDI equilibrium, MNEs have the possibility to reduce unit costs by free-riding on the research produced by the competitor.

APPENDIX

A Equilibrium outputs and prices with asymmetric spillovers

Equilibrium outputs resulting in the last stage of the game are given by:

$$\hat{q}^{DD}_{i,I} = \hat{q}^{DD}_{i,II} = \frac{3\,\gamma(a-A)[3\,b\,\gamma - 4\,\theta^2\,(2-\alpha_i)(1-\alpha_i)]}{\Psi} \qquad i = 1,2 \tag{31}$$

In order to guarantee the existence of a positive equilibrium solution for quantities, it must hold that $[3\,b\,\gamma - 4\,\theta^2\,(2-\alpha_i)(1-\alpha_i)] > 0, \quad i = 1,2$. Notice that these very same conditions ensure also the positivity of equilibrium investments as given in (8).

Taking into account equilibrium quantities it is then possible to calculate equilibrium prices:

$$\hat{p}^{DD}_{I} = \hat{p}^{DD}_{II} = a - \frac{6b\gamma(a-A)[3b\gamma - 2\theta^2((2-\alpha_1)(1-\alpha_1) + (2-\alpha_2)(1-\alpha_2))]}{\Psi} \tag{32}$$

B Equilibrium strategies for sales and equilibrium prices (EE versus DD duopoly)

We begin with the case of a duopoly with two exporting firms, having that:

- sales of each firm in its own country:

$$\tilde{q}^{EE}_{1,I} = \tilde{q}^{EE}_{2,II} = \frac{3\,\gamma(a-A)}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} + \frac{s\,(3\,b\,\gamma - 2\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)}{b\,(9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)} \tag{33}$$

- sales of each firm abroad:

$$\tilde{q}_{1,II}^{EE} = \tilde{q}_{2,I}^{EE} = \frac{3\,\gamma(a-A)}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} - \frac{2\,s\,(3\,b\,\gamma - (2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)}{b\,(9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)} \tag{34}$$

We then substitute one of our assumptions on spillovers localization, that is $\alpha_i^{DD} = \alpha_j^{DD} = \alpha^{DD},\ i,j = 1,2$, into equilibrium outputs obtained at the last stage of the game in the DD case (see Eq. 31). We get

$$\tilde{q}_{i,I}^{DD} = \tilde{q}_{i,II}^{DD} = \frac{3\,\gamma(a-A)}{9\,b\,\gamma - 4\,(2-\alpha^{DD})\,(1+\alpha^{DD})\,\theta^2} \quad i = 1,2 \tag{35}$$

Recalling that $\alpha_i^{DD} = \alpha_j^{DD} = \alpha^{DD} > \alpha_i^{EE} = \alpha_j^{EE} = \alpha^{EE}$, the following proposition can be stated:

Proposition 6. *In an international duopoly with localized spillovers, sales by each firm both in its home country and abroad are higher if the firm is a MNE rather than an exporter.*

Proof of Proposition 6. Let us define $\Theta^K = \frac{3\gamma(a-A)}{9b\gamma-4(2-\alpha^K)(1+\alpha^K)\theta^2}$,with $K \in \{DD, EE\}$. Therefore, taking into account sales in their own country by each firm in a MNE duopoly and in an exporting duopoly respectively we have that $\tilde{q}_{1,I}^{EE} - \tilde{q}_{1,I}^{DD} = \tilde{q}_{2,II}^{EE} - \tilde{q}_{2,II}^{DD} = (\Theta^{EE} - \Theta^{DD}) - \frac{s(3b\gamma-2\theta^2(2-\alpha^{EE})\,(1+\alpha^{EE})}{b(9b\gamma-4\ (2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)}$. Focusing on the case of strategic substitutes (i.e. $\alpha^K < 0.5$), we get that $\frac{\partial\Theta^K}{\partial\alpha} = \frac{-3\gamma(a-A)4\theta^2(2\alpha-1)}{(9b\gamma-4\ (2-\alpha)\,(1+\alpha)\,\theta^2)^2} > 0$. Hence $\tilde{q}_{1,I}^{EE} < \tilde{q}_{1,I}^{DD}$ e $\tilde{q}_{2,II}^{EE} < \tilde{q}_{2,II}^{DD}$. Likewise, considering sales abroad by each firm we can write $\tilde{q}_{1,II}^{DD} - \tilde{q}_{1,II}^{EE} = \tilde{q}_{2,I}^{DD} - \tilde{q}_{2,I}^{EE} = (\Theta^{DD} - \Theta^{EE}) + \frac{2s(3b\gamma-2\theta^2(2-\alpha^{EE})\,(1+\alpha^{EE})}{b(9b\gamma-4\ (2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2)} > 0$

$\square$

As a corollary of the above proposition, it is easily inferred that the level of aggregate production obtained for the DD case ($\tilde{q}_{i,I}^{DD} + \tilde{q}_{i,II}^{DD},\ i = 1,2$) is larger than the corresponding aggregate level of sales obtained under the EE market structure ($\tilde{q}_{i,I}^{EE} + \tilde{q}_{i,II}^{EE},\ i = 1,2$).

Equilibrium prices in the EE case, taking into account once again the hypotheses on spillovers localization, are given by:

$$\tilde{p}_I^{EE} = \tilde{p}_{II}^{EE} = a - \frac{6b\,\gamma(a-A)}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} + \frac{3b\gamma s}{9\,b\,\gamma - 4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} \tag{36}$$

while in the DD case they are as follows:

$$\tilde{p}_I^{DD} = \tilde{p}_{II}^{DD} = a - \frac{6b\,\gamma(a-A)}{9\,b\,\gamma - 4\,(2-\alpha^{DD})\,(1+\alpha^{DD})\,\theta^2} \tag{37}$$

The outcome of a comparison of equilibrium prices is illustrated in the following proposition:

Proposition 7. *In an international duopoly with localized spillovers, equilibrium price is higher if both firms are exporters than when they both are MNEs .*

Proof of Proposition 7. Recalling that we defined $\Theta^K = \frac{3\gamma(a-A)}{9b\gamma-4(2-\alpha^K)(1+\alpha^K)\theta^2}$ with $K \in \{DD, EE\}$, and that, as already shown in the proof of Proposition 4, $(\Theta^{DD}-\Theta^{EE}) > 0$, we have that $\tilde{p}_I^{DD} - \tilde{p}_I^{EE} = \tilde{p}_{II}^{DD} - \tilde{p}_{II}^{EE} = -2b(\Theta^{DD}-\Theta^{EE}) - \frac{3b\gamma s}{9\,b\,\gamma-4\,(2-\alpha^{EE})\,(1+\alpha^{EE})\,\theta^2} < 0.$ □

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