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# International R&D Spillovers and the Absorptive Capacity of Multinationals

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**Abstract**:
This paper studies R&D spillovers as a motive for firms to go multinational. The establishment of a foreign subsidiary may increase a firm's ability to learn from foreign R&D activity since R&D spillovers between firms are moderated by geographical distance. As opposed to earlier studies on this subject, we also model the concept of absorptive capacity where spillovers are endogenised as a function of the firms' own R&D investments. We employ a three-stage Cournot duopoly model to identify under what conditions a firm chooses to service a foreign market through exports or localised production (going multinational). With exogenous R&D investments, the absorptive capacity effect contributes to increase the gains from going multinational when the firm is a technology leader in terms of R&D. If R&D investments are endogenous, only medium-sized absorptive capacity effects will result in firms going multinational. Also, higher spillover rates do not necessarily drive down R&D and profits for the multinational firm. This stands in contrast to models that ignore the aspect of absorptive capacity.

**Keywords**: International R&D spillovers, multinationals, absorptive capacity

**JEL classification code**: F21, F23, L13,O31

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# 1. Introduction

During the last decades, foreign direct investment (FDI) and the multinationalisation of firms have come to play an increasingly important role in the world economy. Compared to trade growth, FDI growth figures were more than twice as large over the period 1980 to 1996. To explain this changing pattern of international transactions, it has become necessary to thoroughly investigate the motives behind the multinationalisation of firms. Although the developing world is receiving a growing share of foreign investments, the vast majority of FDI activities still relate to investment flows between industrialised countries. According to van Aarle (1996), intra-EU FDI among the EU countries has actually gained importance relative to extra-EU FDI. This fact partly undermines the more traditional view on FDI motives, stating that multinationals are attracted to regions where labour as well as capital costs are relatively low.[1] In addition, the gradual removal of trade barriers between industrialised countries also reduces the gains from FDI as a means to avoid tariffs or trade costs (the tariff-jumping argument). In other words, although the traditional incentives for FDI have become gradually weaker, FDI activity between industrialised countries is still growing surprisingly fast.

This observation has provoked a search for additional motives behind FDI between industrialised countries. The growing economic literature on technology diffusion and knowledge externalities contains a large number of studies that focus on industrial location. Empirical studies by e.g. Henderson, Jaffe and Trajtenberg (1993) and Maurseth and Verspagen (1999) give strong support to the existence of geographically limited or localised knowledge spillovers. On this background, there is good reason to expect that firms may tend to cluster or agglomerate geographically when the industry is attached with significant positive knowledge externalities.[2] Such industrial clusters are not necessarily only national in scope. They may just as well attract foreign firms that see the need to establish a subsidiary in order to keep up with the innovative activities in the industry. A good example in this context is the strong international agglomeration of

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[1] Naturally, one may provide a long list of alternative explanatory factors behind FDI flows, including natural resources, market growth potential, exchange rate expectations, political stability, strategic acquisitions etc.

[2] Similarly, several studies of the host country effect of multinationals have explicitly considered the importance of technology learning in developing countries. See e.g. Grossman and Helpman (1991).

firms in Silicon Valley where companies from more than 80 countries are represented. In the literature, this motive behind FDI has been named *technology sourcing through foreign direct investment*, and the motive plays a key role in this paper.

Over the last 10 years, several empirical studies have focused on host country R&D activities as a motive for FDI, both measured in terms of greenfield investments (new plants etc.) and through international mergers and acquisitions. The studies by Kogut and Chang (1991), Anand and Kogut (1997), Neven and Siotis (1996), Braunerhjelm and Svensson (1996) and Fors (1998) all give empirical support to technology sourcing as a motive for FDI.[3] Within the international business literature, Shaver (1998) and Shaver and Flyer (2000) have also collected evidence supporting the same motive. Recently, however, Braconier, Ekholm and Knarvik (2001) have presented an econometric study where such motives are not identified.

Unfortunately, the number of theoretical contributions with focus on this issue is more limited. In two papers by Fosfuri and Motta (1999) and Bjorvatn and Eckel (2001), the commonly held view that multinationals have a competitive advantage that they exploit in foreign markets is challenged. Using a two-country Cournot duopoly model where firms may choose to service their foreign market either through exports or FDI, the authors show that firms may go multinational although they have a technological disadvantage (are less R&D intensive) as compared to the foreign rival firm. The reason is that technology or alternatively R&D is believed to spill over to the technology follower with a certain probability as long as the follower goes multinational.[4] In a rather similar model, Siotis (1999) provides the same conclusions, yet he allows spillovers to run both ways between the technology leader and the follower. Petit and Sanna-Randaccio (2000) brings this type of models one step further when they endogenise both the foreign entry decision (exporting or going multinational) and the R&D investment decision (technology level of the firm). The model shows that multinational firms are the ones that invest most in R&D as compared to firms that choose to export. However, firms are symmetric and R&D spillover rates are of the same size whether the firms engage in

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[3] For an extensive survey of the empirical literature on R&D spillovers as a motive for FDI, see Grünfeld (2002).

[4] That is, the authors assume that there are no R&D spillovers through exports.

exports or FDI. Thus, the idea of R&D spillovers as a motive for going multinational is not thoroughly explored in this paper. Finally, De Bondt, Sleuwaegen and Veugelers (1988) model the R&D behaviour of a multinational using a Cournot duopoly model where the R&D investment decision is endogenised, allowing for asymmetric spillover rates. But as opposed to the other studies, the decision on whether to service the foreign market through exports or FDI is not considered. The model shows that multinational firms tend to invest more in R&D than purely domestic firms, and the larger the market size is both at home and abroad, the more R&D intensive will the multinational be, relative to the domestic firm.

A common weakness in models that study the effect of technology spillovers using game theory, is the fact that they ignore the absorptive capacity dimension of R&D investments. When the rate of R&D spillovers is treated as exogenous, one implicitly assumes that knowledge flows to the firm as some kind of ‘manna from heaven’. In other words, the firm does not have to engage in any form of costly learning or search process in order to gain from the positive R&D externalities. In Cohen and Levinthal (1989) as well as in a large strand of literature within the fields of organisation and management, it is common wisdom that firms are only able to utilise the knowledge externalities deriving from the R&D of other firms if they invest in R&D themselves. The reason is simply that you need relevant knowledge in order to understand, decodify and absorb the R&D information that comes from other firms. Indeed, Cohen and Levinthal (1989) finds strong empirical evidence supporting the idea that more R&D intensive firms are better in absorbing R&D spillovers. In Grünfeld (2001), absorptive capacity effects are analysed in a symmetric Cournot duopoly game. Here it is shown that when firms behave strategically, weak absorptive capacity effects give a positive incentive to invest in R&D as compared to models where the rate of R&D spillover is exogenous. However, strong absorptive capacity effects (i.e., when small R&D investment provide large spillovers) tend to discourage R&D investments.

In this paper, we explicitly include the concept of absorptive capacity in an international Cournot duopoly model where one firm only serves its domestic market while the other is a foreign firm that chooses to serve this market either through exports or the establishment of a multinational subsidiary through FDI. In order to analyse the consequences of including absorptive capacity effects, we start out with a simple 2 stage version of the model with exogenous R&D levels of firms, and then introduce more complex versions where the R&D investment of firms is endogenous.

In the most simple model version where both the R&D level of firms and the R&D spillover rate are given exogenously, a firm will be discouraged from going multinational when it is a technology leader in terms of relatively high R&D investments. The reason is simply that going multinational increases the spillover rate due to localised externalities, and since there is relatively little to learn from the competing domestic firm, the benefits will be outweighed by the increased leakage of R&D results to the competitor. This is consistent with the outlined technology sourcing hypothesis, but somewhat hard to accept since we know that multinationals most often are characterised by technological leadership and disproportionately large R&D investments. When we incorporate absorptive capacity effects, this result is modified. The absorptive capacity mechanism generates asymmetric spillover rates where the technology leader gets the advantage of a higher rate. This implies that R&D-rich firms may find it more profitable to go multinational, which is consistent with the aforementioned characteristic of multinationals. We also find that if the foreign firm is a technology follower, or alternatively, not too superior with respect to R&D investment, a higher spillover rate (both with and without absorptive capacity effects) increases the gains from going multinational.

When a third stage is introduced in the model where firms first set the optimal R&D investment level, the foreign firm always finds it optimal to be a technology leader, investing more in R&D than the domestic firm. This is due to the fact that the foreign firm serves two markets whereas the domestic firm only serves its home market. Hence, the whole idea of technologically less advanced firms that go multinational in order to gain from R&D spillovers, becomes infeasible. Conclusions regarding how the foreign firm chooses to service its foreign market remain unchanged if we restrict ourselves to exogenous R&D spillover rates. However, when we impose absorptive capacity effects, the pattern changes. The foreign firm will choose to export if the absorptive capacity effect is *weak* or *strong*. It is only for *intermediate* absorptive capacity effects that the foreign firm will choose to go multinational. This pattern is driven by the fact that a strong absorptive capacity effect is more gainful to the domestic firm than to the foreign firm, driving up the relative equilibrium R&D level of the domestic firm which contributes to cut production costs. In short, the absorptive capacity mechanism generates two opposing effects on R&D investment and profits. On the one hand, a stronger absorptive capacity effect improves the productivity of R&D investments since learning becomes easier. On the other hand, a strengthening of this effect also improves the competitor's ability to learn, producing the well-known negative effect of spillovers on R&D investment as outlined by e.g. d'Aspremont and Jacquemin (1988). This negative effect dominates when the absorptive capacity effect is large, cutting profits from going multinational below the profits derived from exporting.

The baseline model is presented and discussed in Section 2. Section 3 introduces the absorptive capacity mechanism. In Section 4, we focus on the simplest version of the model where the R&D level of firms is given. Section 5 expands the model in order to allow for endogenous R&D investments. Section 6 concludes and provides policy implications and prospects for future research.

## 2. The model set-up

The model is based a Cournot duopoly game, describing two firms that have their home base in separate countries. The domestic firm (*d*) is only supplying its home market *D* whereas the foreign firm (*f*) supplies its home market *F* as a monopolist as well as the market *D*. Ideally, we should let both firms be able to supply their foreign market, but when we endogenise the R&D investment decision of firms, such a model will produce symmetric equilibria. In other words, unless we impose additional asymmetries that complicate the model drastically, firms will have the same technology levels and choose the same foreign market entry strategy as well as output volumes. This is not a desirable property since we are concerned with multinationalisation motivated by R&D and technology differences.

The model is based on a three-stage game. In the first stage, the foreign firm *f* decides whether to service market *D* through exports (*e*), going multinational through establishing a foreign subsidiary (*m*) or not to service market *D* at all *(n)*. The model is designed so that the domestic firm will always choose to produce. If otherwise, there would exist no potential for R&D spillovers. In the second stage, firms decide upon the optimal cost-reducing R&D level $x_f$ and $x_d$, representing firm *f* and *d* respectively. Finally, both firms compete in the output market where outputs $q_f$ and $q_d$ are homogeneous products. The foreign firm's strategy choice is denoted ($s_f$=*n,e,m*) as described above.

Firm *d* has the following profit function if the foreign firm supplies its market *D* through going multinational ($s_f$=*m*)[5]:

**(1)** $$p_d^m = (p^m - c_d^m)q_d^m - 2x_d{}^2$$

where *p* is the price in market *D* and the R&D investment cost function represented by the last element on the right-hand side is quadratic in order to ensure an interior

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[5] Here we only present the profit function for the domestic firm when it chooses to produce since the case where *sd=n* gives zero profit.

solution.[6] The variable $c_d^m$ represents the unit cost function defined as follows for both firms:

**(2)** $$c_i^m = b - x_i - h_i x_j \quad 0 \leq h_i \leq 1 \quad i = d, f$$

The R&D spillover rate parameter $h$ tells us the proportion of the firm's R&D that spills over to the other firm. The closer $h$ is to 1, the larger is the proportion of R&D results that leaks out to the competitor. Since R&D levels enter as a component in the marginal cost function, R&D is modelled as cost reducing through process innovations. Throughout the paper, the exogenous R&D spillover rate $h$ is assumed equal for both firms. $b$ is a constant marginal cost component which ensures that marginal costs are non-negative. The price in market $D$ is given by the following simple linear inverse demand function:

$$p = a - q_d - q_f$$

where $a$ is a parameter describing the market size. Now, if the foreign firm decides to supply market $D$ through exports we assume for simplicity that there are no spillovers and the unit cost function will be given by $c_d^e = b - x_d$. The idea that there are no R&D spillovers when the foreign firm exports may seem overly restrictive since we know from the empirical literature (see e.g. Coe and Helpman (1995) that trade flows tend to affect the knowledge base and productivity of firms due to so-called embodied R&D spillovers. In this study, we are concerned with the idea that R&D is more easily transferred between firms that are located close to each other. Hence, spillovers will be higher under FDI than under exports. In principle we could allow R&D spillovers through exports, but we lose no important information if we benchmark the export-related R&D spillovers to zero.

The profit function for the foreign firm has the following structure when it supplies market $D$ through going multinational ($s_f = m$) :

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[6] The degree of convexity of the R&D cost function is determined by the scalar which is chosen to be 2 in this exercise. A higher value will reduce the equilibrium R&D investment level, whereas smaller values than 2 do not ensure that we fulfil the second-order conditions.

$$p_f^m = (P^m - C^m)Q^m + (p^m - c_f^m)q_f^m - 2x_f^2 - G \tag{3}$$

Remember that the foreign firm is a monopolist in its home market *F*, where it produces output *Q* and the monopoly price is denoted *P* (capital letters). Furthermore, it faces a fixed investment cost *G* associated with the establishment of a foreign subsidiary. The unit cost functions $C^m$ and $c_f^m$ are given by (2). If the foreign firm chooses strategy ($s_f$=*e*), the following profit function applies:

$$p_f^e = (P^e - C^e)Q^e + (p^e - c_f^e - t)q_f^e - 2x_f^2 \tag{4}$$

Here the firm will face a unit trade cost *t* when it is exporting to market *D*, and once again there are no spillovers associated with exports. As pointed out by e.g. Smith (1987), the decision on whether to export or go multinational must be based on the size of the variable cost component *t* relative to the fixed cost component *G*. Since the R&D spillovers affect unit costs, it is clear that the spillovers also affect the decision whether to export or to go multinational.

The model is solved using backwards induction, first identifying the Nash-Cournot equilibrium output levels and then identifying the subgame perfect equilibrium (SPE) R&D levels and entry modes. The subgame perfect output configurations are given by:

$$\begin{aligned}
&q_i^m{*} = \frac{1}{3}\left(b + 2x_i - x_j + (2h_i x_j - h_j x_i)\right) \quad i = d,\, f \\
&q_d^e{*} = \frac{1}{3}\left(b + 2x_d - x_f + t\right) \qquad q_f^e{*} = \frac{1}{3}\left(b + 2x_f - x_d - 2t\right) \\
&Q^m{*} = \frac{1}{2}\left(b + x_f + h_i x_d\right) \qquad \mathrm{Q}^e{*} = \frac{1}{2}\left(b + x_d\right)
\end{aligned} \tag{5}$$

where and asterisk represents equilibrium levels. Throughout the paper we interpret the parameter *b*=*a*-*b* as the market size and it is assumed to be positive in order to provide positive outputs. From the inverse demand function we have that consumers demand more for a given price when *a* is higher. We also assume that the market size is similar in both markets to avoid too many asymmetries in the model. If firm *f* chooses not to supply market *D* at all, firm *d* will operate as a monopolist and produce output similar to the output provided at home by firm *f*.

A core question is: under what conditions do the R&D spillovers contribute positively to the equilibrium output and profits of firms? If the firm is a multinational and spillovers are symmetric $h_i = h_j$, we see from (5) that R&D spillovers contribute positively to output of firms in market *D* if :

$$x_i < x_i' = 2x_j.$$

In other words, the multinational firm will only find R&D spillovers gainful if its R&D level is no more than twice as large as its competitor's. If not, the amount of R&D spillovers running from the multinational firm to the domestic firm is less than the spillovers running the opposite way. The reason is simply that there is not enough domestic firm R&D to learn from. This result suggests that R&D spillovers only contribute to more multinationalisation as long as the firms that plan to go multinational are not too technologically advanced. Clearly, since the foreign firm shares its knowledge pool in both markets, the spillovers also contribute to reduced costs at home, thus reducing the critical size of $x_f'$ that determines whether spillovers contribute positively to profits.

## 3. The absorptive capacity mechanism

As mentioned in the introduction, the traditional way of approaching the problems related to R&D spillovers is to operate with exogenous spillover. However, this is basically the same as treating spillovers as some kind of 'manna from heaven' that has no costs associated to them. In order to deal with this shortcoming, we endogenise the R&D spillover rate, making it a function of the R&D level of the spillover-receiving firm. In order to distinguish between the exogenous R&D spillover rate and the endogenous R&D spillover rate generated by the absorptive capacity mechanism, we denote the latter with $g_i$, $i=d,f$.

First of all, we wish to satisfy the condition stating that $0 \leq g_i \leq 1, \;\; i = d, f$ . If $g_i > 1$, a firm has a stronger economic gain from its competitor's R&D than its own R&D investments. This specification could be relevant if firms invest in complementary R&D activities, such that external and somewhat different R&D output add strongly to the effects of own R&D activities. However, such a specification introduces a new dimension to the model which severely complicates the analysis. If $g_i < 0$, we have a case where the competitor's R&D investment not only affects firm profits negatively through the output market as the competitor's costs are reduced, but it also has a direct negative effect on the firm's cost function. This could be relevant if firms e.g. involve in some kind of patent race where the likelihood of losing the race is an increasing function of the competitor's R&D investments. However, such a specification removes all learning effects of own R&D from the model, and introduces a negative externality as opposed to the positive externality we usually relate to the term knowledge or R&D spillovers.

Second, we are searching for a functional form that allows the marginal absorptive capacity effect to be decreasing in the firm's own R&D investments. In other words, the marginal increase in the ability to learn from the R&D undertaken by the competitor shall be larger when you invest one more dollar at a low R&D level as compared to one more dollar invested at a high R&D level. A simple functional form that satisfies these two requirements is given by:

**(6)** $$g_i(x_i, a) = \frac{ax_i}{1+ax_i} \qquad a \geq 0, \quad x_i > 0$$

The parameter *a* is a parameter that scales the size of $\partial g_i / \partial x_i$. If *a=0*, the firm is not able to absorb any of the external R&D spillovers and own R&D investments do not help the firm to learn. The higher *a* is, the easier will the firm learn from external R&D through own R&D investment. Thus, the parameter says something about the efficiency of own R&D investments in promoting absorptive capacity. That is, *a* is a ***learning parameter*** that tells us how much the firm's R&D helps learning from the R&D undertaken by the competitor.[7] First, observe that the absorptive capacity function (5) has the following limit properties:

$$\lim_{x_i \to \infty} g_i(x_i, a) = 1 \quad \text{and} \quad \lim_{x_i \to 0} g_i(x_i, a) = 0$$

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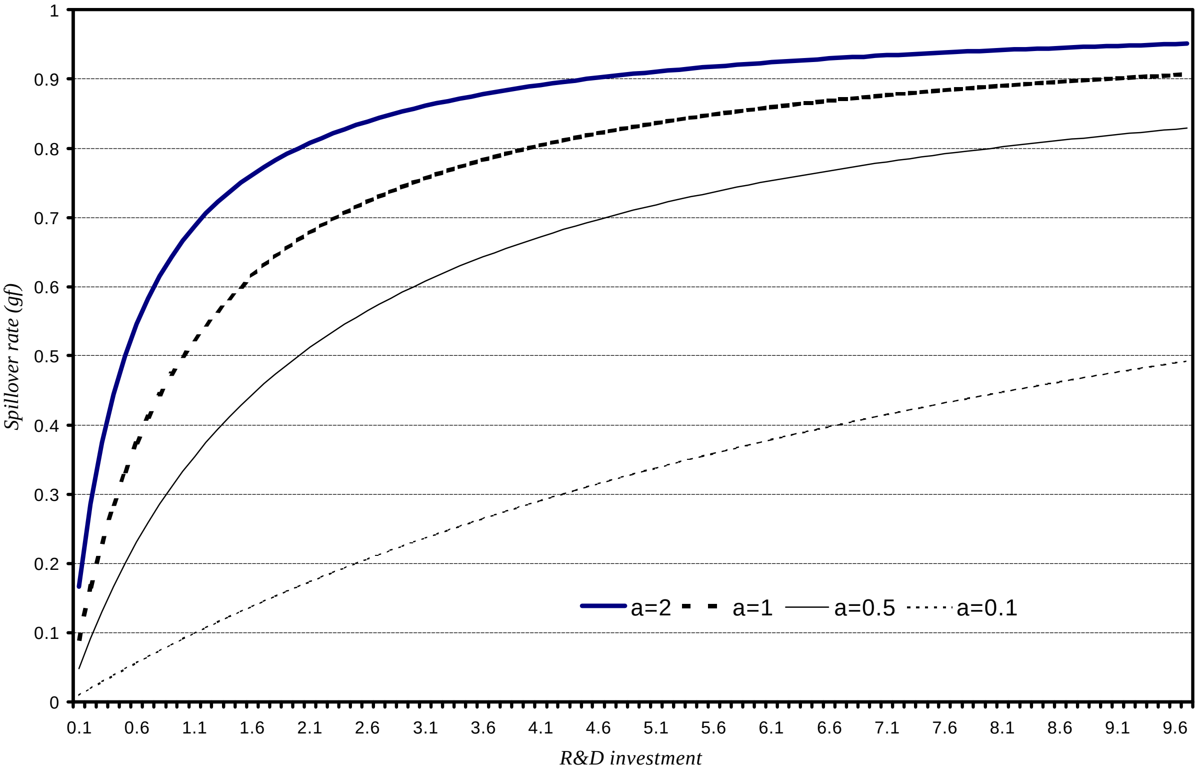
[7] Cohen and Levinthal (1989) apply a related procedure where their parameter β describes the characteristics of outside knowledge that makes R&D more or less critical to absorptive capacity. The difference, however, lies in modelling of absorptive capacity on the one hand and spillovers on the other. In our model, we treat these two effects as integral parts of the effective R&D, whereas Cohen and Levinthal explicitly separate them.

Hence, the absorptive capacity function satisfies the desired restrictions on R&D spillovers. In Figure 1, we illustrate how the absorptive capacity function varies in *a* and $x_i$. Figure 1 shows that higher R&D investments imply that the firm gains a stronger absorptive capacity, and the absorptive capacity is an increasing function of the scaling parameter *a*.

**Figure 1: The absorptive capacity function**



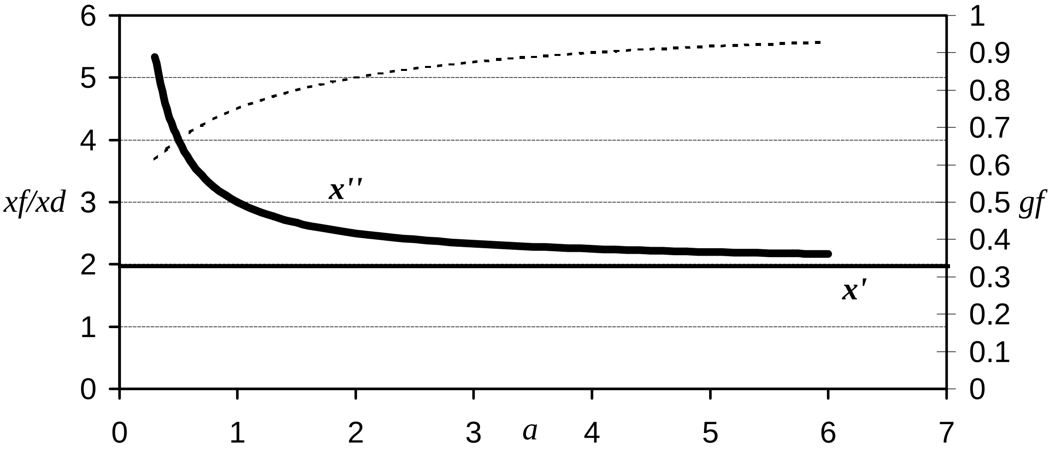
A possibly more realistic but also more complex learning function is the one that is based on the logistic learning curve, where the marginal gain from investing in learning capacity is small for low investment levels (see e.g. Kashenas and Stoneman (1995) for more on this). Since the logistic function is more complex, the equilibrium R&D investments and foreign market servicing strategies become hard to calculate and interpret. Thus, we choose the more simple concave function in (6).

Inserting (6) into (5), illustrates how the absorptive capacity mechanism affects the condition for whether R&D spillovers contribute positively to output for firms in market *D*:

$$(7) \qquad \frac{2ax_i x_j}{1+ax_i} - \frac{ax_i x_j}{1+ax_j} > 0 \qquad \Leftrightarrow \qquad x_i < x_i'' = 2x_j + \frac{1}{a}$$

Since the learning parameter *a* is a positive constant, we know that $x_i''>x_i'$. The condition in (7) is graphically illustrated with the thick line in Figure 2, while the dotted line represents the corresponding spillover rate $g_f$.

**Figure 2: Critical combination of relative R&D levels and a for which R&D spillovers contribute positively to the multinationals output**



The absorptive capacity mechanism makes R&D spillovers contribute positively to output and profits for a wider range of differences in R&D levels as compared to the case with exogenous and symmetric R&D spillover rates. More specifically, for small absorptive capacity effects, the multinational firm may still gain from spillovers although it is a strong technology leader. This is due to the fact that the absorptive capacity of the multinational becomes larger than the domestic firm's. Consequently, spillover rates become asymmetric and favour the multinational when it is a technology leader.

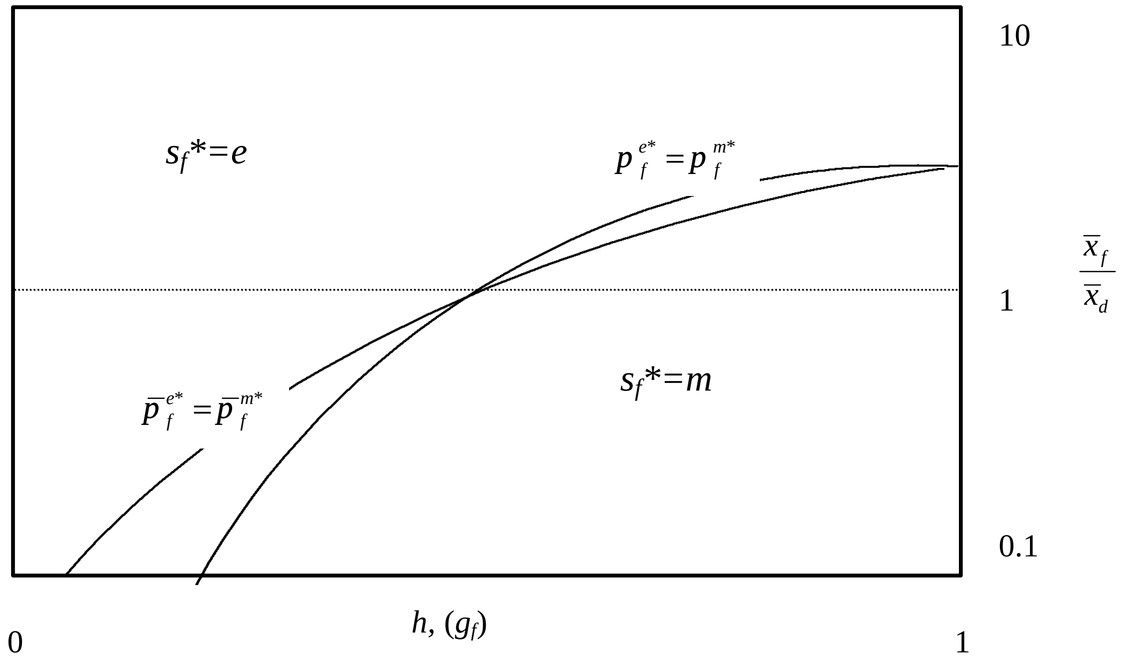
## 4. Model with exogenous R&D investments

We start out with studying how the absorptive capacity mechanism affects the equilibrium entry strategy of firm *f*, assuming that the R&D levels are given. This implies that the model is reduced to a two-stage game where the R&D investment stage is excluded. Inserting the equilibrium output levels of firm *f* from (5) into the profit functions in (3) and (4) and dropping the R&D investment cost function,[8] provides us with the following equilibrium profit functions when the R&D spillover rate is exogenous, i.e., no absorptive capacity effects:

$$
\begin{aligned}
\bar{p}_f^{m*} &= \frac{1}{9}(b+2-\bar{x}_d+(2\bar{x}_d-1)h)^2+\frac{1}{4}(b+1+h\bar{x}_d)^2-G \\
\bar{p}_f^{e*} &= \frac{1}{9}(b+2-\bar{x}_d-2t)^2+\frac{1}{4}(b+1)^2
\end{aligned}
\tag{8}
$$

Here, the R&D level of firm *f* is set to $x_f$=1, without losing any generality. In order to separate the notation in the model with exogenous R&D levels from the later models with endogenous R&D levels we ascribe a bar to the variables.

**Figure 3: The foreign firm's equilibrium market servicing strategy**



Since the R&D spillovers link the two markets together, it becomes necessary to use numerical simulations to identify the equilibrium entry strategies. These strategies are also a function of the parameters, which are benchmarked to the following values:

$$G=5 \quad b=10 \quad t=0$$

In the following analysis, we let trade costs ($t$) be ignorable and equal to zero. This implies that the decision on whether to export or go multinational becomes purely a function of the gains from R&D spillovers weighed against the fixed cost ($G$) associated with going multinational. The presence of trade costs implies that exporting profits are scaled down, which may induce a tariff or trade cost jumping argument for FDI. However, the intention of this paper is not to focus on tariff jumping, but to investigate the relationship between R&D spillovers and multinationalisation. Since we know that higher trade costs unambiguously favour FDI in this kind of model, we lose no analytical insight by setting $t=0$.

In Figure 3, the equilibrium entry strategies are depicted as a function of the R&D spillover rate on the horizontal axis and the relative R&D intensity of firms on the vertical axis. Firm *f* will choose to export if the spillover rate is small regardless of the firm’s relative R&D level (see the far-left side of Figure 3). This is the case when the positive contribution to profits from R&D spillovers is outweighed by the negative effect of $G$. When firm *f* has a low relative R&D level, a higher spillover rate increases the gains from going multinational, since the gains from R&D spillovers are larger for firm *f* than for firm *d*. The indifference curve $\bar{p}_f^{e*} = \bar{p}_f^{m*}$ represents combinations of spillover rates and relative R&D levels where the foreign firm is indifferent between exporting or going multinational through localised production. For any given spillover rate ($h$), a higher relative R&D level of firm *f* will drive down the profits of going multinational relative to exporting, since firm *f* gets relatively less to learn from, whereas firm *d* experiences a relatively larger pool of R&D to learn from. This explains the positive slope of the $\bar{p}_f^{e*} = \bar{p}_f^{m*}$ curve.

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[8] We drop R&D investment cost considerations since the investment level is given in this model version.

If firm *f* is a strong R&D leader, the gains from going multinational relative to exporting becomes a decreasing function of *h* since the leakage of R&D results is larger than the R&D spillovers running to the firm.[9] Hence, for large relative R&D levels, firm *f* will never find it optimal to go multinational.

It is important to notice that when $x_f/x_d$ is small, firm *f* may not find it profitable to supply market *D* at all, i.e. $s_f{}^*=n$. However, in order to keep the graphic analysis simple, we choose parameter values and restrict the relative R&D intensity of firm *f* registered on the vertical axis to start at 0.1, such that $\bar{p}_f^{e*} \geq \bar{p}_f^{n*}$.

Notice also that the foreign firm is fully allowed to go multinational but to choose not to supply market *D* with any output. This can be profitable if the foreign firm has a low R&D level relative to the domestic firm. In that case, it will reduce the unit cost in its home market *F* and if this cost reduction outweighs the fixed investment cost *G*, this strategy is profitable. Such a strategy is purely based on the technology sourcing motive and is best illustrated by a firm that invests in a pure R&D unit abroad in order to gain from the localised R&D spillovers. In other words, the investment is purely meant to improve the absorptive capacity of the firm. However, this form of investment behaviour can only be understood in a context where the absorptive capacity mechanism is modelled explicitly. Inserting the absorptive capacity mechanism from (6) into (8) gives the following profit functions:

$$\begin{aligned} &\bar{\Pi}_f^{m*} = \frac{1}{9}\left[b+2\left(1+g_f\bar{x}_d\right)-\bar{x}_d-g_d\right]^2+\frac{1}{4}\left[b+1+g_f\bar{x}_d\right]^2-G \\ (9)\qquad &\bar{\Pi}_f^{e*} = \frac{1}{9}(b+2-\bar{x}_d)^2+\frac{1}{4}(b+1)^2 \end{aligned}$$

where we use upper case letter $\Pi_i$ in order to distinguish the models with and without absorptive capacity effects. Notice that since $\bar{x}_f = 1$, we have that $g_f = a/(1+a)$ and $g_d = a\bar{x}_d/(1+a\bar{x}_d)$. Also, notice that we have dropped the trade cost component in the

---

[9] Notice that since the foreign firm can utilise the R&D spillovers in its home market, an increase in the spillover rate (*h*) will still be gainful in the case where the firm has a moderate technological advantage, i.e. $x_f/x_d$ is slightly larger than 1.

expression for exporting profits, since *t=0*. As there are no spillovers under exports, we have that $\bar{p}_f^{e*} = \bar{\Pi}_f^{e*}$ from (8) and (9). Now, comparison of profits from going multinational in the two cases (8) and (9) gives the following result:

**Result 1:** *If h=g$_f$=a/(a+1), then* $\bar{x}_d > 1 \ => \ \bar{p}_f^{m*} > \bar{\Pi}_f^{m*}$ *while* $\bar{x}_d < 1 => \bar{p}_f^{m*} < \bar{\Pi}_f^{m*}$.

**Proof of Result 1:**

If we let *h=g$_f$=a/(a+1),* we have from (8) and (9) that

$$\bar{p}_f^{m*} > \bar{\Pi}_f^{m*} \quad => \quad \frac{1}{1+a} < \frac{a\bar{x}_d}{1+a\bar{x}_d} \quad =>$$

$$a + a^2\bar{x}_d < (1+a)a\bar{x}_d \quad => \quad \bar{x}_d > 1 \qquad \square$$

The result states that if the domestic firm is the technology leader in terms of R&D investment, the absorptive capacity mechanism will drive down profits relative to the case with exogenous R&D spillover rates. On the other hand, if the foreign multinational firm is the technology leader, the mechanism will contribute to higher profits. The reason is simply that going multinational when the domestic firm is the technology leader, implies that R&D spillovers flowing from the multinational firm will be larger in the case with absorptive capacity effects, since the domestic firm is able to absorb more than the multinational is. This effect is illustrated by the shift in the indifference curve from $\bar{p}_f^{e*} = \bar{p}_f^{m*}$ to $p_f^{e*} = p_f^{m*}$ in Figure 3. In the figure, the size of the spillover rate on the horizontal axis corresponds both to the case with exogenous spillover rates (*h*) and the case with spillover rates for the foreign firm based on the absorptive capacity mechanism (*g$_f$*). With a very strong absorptive capacity effect, i.e., $a \to \infty$, the spillover rate *g$_i$(a)* converges to 1 for both firms. This implies that profits in the case with and without absorptive capacity effects become the same since *g$_i$(a)=h*=1.

It follows directly from Result 1 that the foreign firm will be more inclined to go multinational as a technology leader when we allow for absorptive capacity effects. This is in line with empirical findings, showing that multinationals often are technology leaders in their industry (see e.g. UNCTAD (1999)). Hence, the empirical relevance of our model specification seems to be in place.

## 5. Models with endogenous R&D investments

In order to study how international investment behaviour is affected by the presence of absorptive capacity effects, it becomes crucial to allow firms to adjust their R&D investment levels, enabling them to directly affect their own absorptive capacity. Thus, we now expand the model, allowing both firms to adjust R&D investments in order to maximise profits. In order to do this properly, we re-introduce the R&D investment cost function outlined in Section 2. In the case with no absorptive capacity effects, the profit functions relating to exports and going multinational are as follows:

$$
\begin{aligned}
p_f^m &= \frac{1}{9}(b+2x_f-x_d+(2x_d-x_f)h)^2+\frac{1}{4}(b+x_f+hx_d)^2-2x_f{}^2-G\\
p_d^m &= \frac{1}{9}(b+2x_d-x_f+(2x_f-x_d)h)^2-2x_d{}^2\\
p_f^e &= \frac{1}{9}(b+2x_f-x_d)^2+\frac{1}{4}(b+x_f)-2x_f{}^2\\
p_d^e &= \frac{1}{9}(b+2x_d-x_f)^2-2x_d{}^2
\end{aligned}
\tag{10}
$$

The 4 first-order conditions $\partial p_i^{s_f} / \partial x_i = 0$ provide the following subgame perfect equilibrium R&D investments:[10]

$$
\begin{aligned}
x_f^{m*} &= \frac{b}{y}\left(37+13h-13h^2+2h^3\right) \qquad & x_d^{m*} &= \frac{b}{y}\left(10+13h-13h^2+2h^3\right)\\
x_f^{e*} &= \frac{1}{214}\left(74b-80t\right) \qquad & x_d^{e*} &= \frac{1}{214}\left(20b+18t\right)
\end{aligned}
\tag{11}
$$

where $y = 107+85h-36h^2+11h^3-2h^4 > 0 \quad \forall h \in [0,1]$.

**Result 2**: *For all b>0,* $x_f^{m*} > x_d^{m*}$

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[10] The second order conditions under the strategy $s_f$ =m are given by: $\partial^2 p_f^m / \partial x_f^2 = 4h^2 - 16h - 47 < 0$ and $\partial^2 p_d^m / \partial x_d^2 = 2h^2 - 8h - 28 < 0$ which are satisfied for all $h \in [0,1]$.

The proof of Result 2 is purely based on a comparison of the expressions in (11). The result that firm *f* always will be the technology leader is due to the fact that the foreign firm supplies both its home *F* market and market *D*, while the domestic firm only supplies its home market *D*. A larger market enables the foreign firm to spread out the R&D costs over larger volumes, giving incentives to invest more in R&D. Observe also that firm *f* will be the technology leader as an exporter.[11]

Result 2 gives valuable insights to the discussion in Section 4 where R&D levels were assumed exogenous. When we allow endogenous R&D investments, the foreign firm will never be a technology follower in equilibrium. Hence, the equilibrium strategy configurations described in the lower part of Figure 3 will never be realised. Consequently, the whole question of whether firms choose to go multinational motivated by R&D spillovers is limited to the case where the multinational is a technology leader. Keeping this in mind, the core question then relates to how firm *f* responds to an environment with higher spillover rates. Taking the derivative of equilibrium R&D with respect to *h*, reveals that:

$$\begin{aligned} &\frac{\partial x_f^{m*}}{\partial h} = \frac{b}{y^2}(-1216h^2 + 350h^3 - 52h^5 + 4h^6 + 149h^4 - 118h - 1754) < 0 \quad \forall h \in [0,1] \\ &\frac{\partial x_d^{m*}}{\partial h} = \frac{b}{y^2}(-2062h - 325h^2 + 149h^4 - 52h^5 + 134h^3 + 4h^6 + 541) \geq 0 \text{ if } h \leq h' \approx 0.254 \end{aligned} \tag{12}$$

Thus, regardless of the market size (*b*), the equilibrium R&D investment of firm *f* is a decreasing function of the exogenous spillover rate *h*. We name this effect the *traditional negative spillover effect* on R&D investment and it is illustrated in Figure 4, where the thin full line describes firm *f*'s R&D investment pattern as a function of the R&D spillover rate (*h*). The intuition behind this result is as follows. Since the optimal R&D level of the foreign firm is larger than for the domestic firm, the leakage of R&D results is more detrimental to profits than the gains through spillovers. As a result, firm *f* will cut down on R&D in order to limit the negative effects of higher R&D spillovers. The result in (12) implies that if there are no trade costs and spillover rates are exogenous, the

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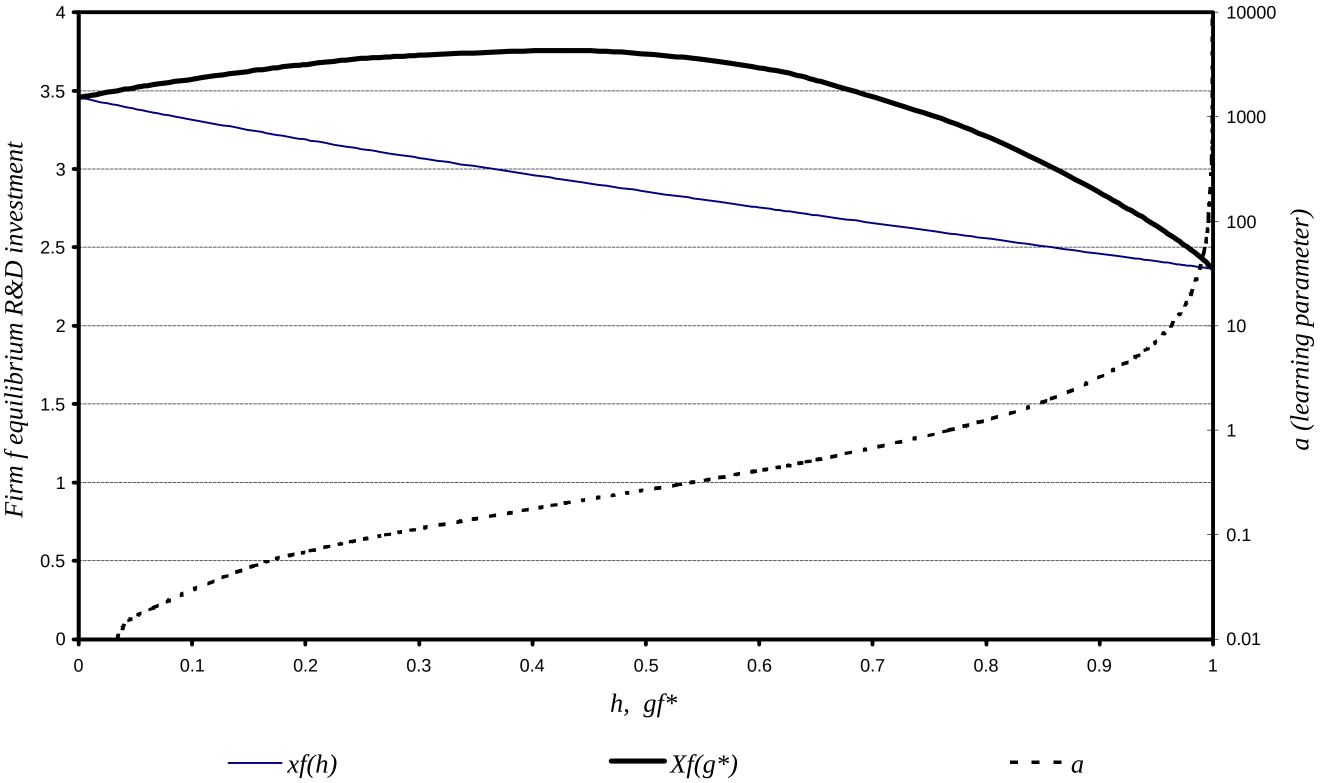
[11] This does not have to be the case if we allow large trade costs.

foreign firm will always invest more in R&D when it is exporting as compared to going multinational, since exporting implies that $h=0$.[12]

**Figure 4: Foreign firm equilibrium R&D investment**

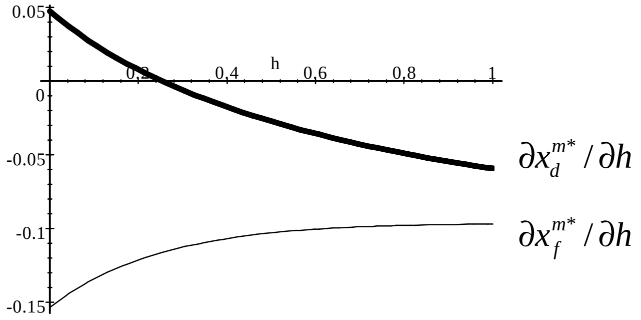


As long as $h<h'$, the domestic firm will respond with higher R&D investment as the spillover rate increases. The fact that firm *f* responds with lower R&D investments as *h* increases, enables the domestic firm to take a larger share of its home market since its cost disadvantage is reduced. With a larger market share, it becomes optimal to invest more in R&D. However, as illustrated in Figure 5, $\partial^2 x_f^{m*} / \partial h^2 < 0$, implying that the marginal cutback of R&D by firm *f* is reduced at higher levels of *h*. This makes it less gainful for firm *d* to invest more in R&D due to this effect. When $h>h'$, the negative effect of R&D leakage also outweighs the positive effect of spillovers for the domestic firm, driving down its equilibrium R&D level.

---

[12] It is important to notice that if we relax the assumption of similar market sizes, e.g. allowing market *F* to be much smaller than market *D*, it is fully possible that the foreign firm's R&D investment level will be an increasing function of *h* as long as *h* is relatively small.

**Figure 5: The derivative of R&D w.r.t. spillover rate (h)**



When we incorporate the absorptive capacity mechanism from (5), the following profit functions apply:

$$\text{(13)} \qquad \begin{aligned} \Pi_f^m &= \frac{1}{9}\Big[b + 2\big(X_f + g_f X_d\big) - X_d - g_d X_f\Big]^2 + \frac{1}{4}\Big[b + X_f + g_f X_d\Big]^2 - 2X_f{}^2 - G \\ \Pi_d^m &= \frac{1}{9}\Big[b + 2\big(X_d + g_d X_f\big) - X_f - g_f X_d\Big]^2 - 2X_d^2 \end{aligned}$$

Similar to the model with exogenous R&D levels, the profit functions under exports are the same as those outlined in (10) since there is no opening for spillovers. As outlined in Section 4, one important consequence of including absorptive capacity effects of R&D, is that we allow spillover rates to differ between firms. The corresponding first order conditions based on (13) are given by:

$$\text{(14)} \qquad \begin{aligned} \frac{\partial \Pi_f^m}{\partial X_f} &= K\big(a, b, X_d, X_f^*(a, b, X_d)\big) = 0 \\ \frac{\partial \Pi_d^m}{\partial X_d} &= L\big(a, b, X_f, X_d^*(a, b, X_f)\big) = 0 \end{aligned}$$

The full specific functions are presented in Appendix 1. Both first order conditions are relatively complex 4. order polynomials in $X_f$ and $X_d$. Since it is not possible to derive informative and easily interpretable explicit solution for equilibrium R&D investments, we analyse the equilibrium R&D investment behaviour running numerical simulations based on the solution to the simultaneous system of equations in (14). The numerical simulations produce several equilibrium solutions to (14), but only one of them provides non-negative and real R&D investments, thus all other solutions are regarded as nonfeasible. In the following discussion, we set the market size parameter $b=10$, yet notice that our results are robust for all values of the market size parameter $b>0$. In Appendix 2, we present sensitivity tests for alternative market sizes by running simulations with different values of $b$.

The simulation results are represented by the thick function in Figure 4 which describes the relationship between equilibrium R&D investments of firm $f$ and the endogenous spillover rate $g_f^*(a,X_f^{m*})$. Figure 4 is designed to compare equilibrium R&D investments in the game with absorptive capacity effects to the game with exogenous spillover rates ($h$). To do this properly, we set $h= g_i^*(a,X_i^{m*})$ on the vertical axis, thus the functions representing R&D investment in the two cases always refer to *the same spillover rate*, however, one is endogenously determined by $X_i$ and $a$, while the other is exogenous. In Figure 4, we also depict the representative value of the learning parameter $a$ (on the right axis), that corresponds to the spillover rate $g_f$*. Naturally, the higher the learning parameter is, the higher is the spillover rate since the firm is able to absorb more external R&D.

**Result 3*:*** *When* $h= g_f^*(a,X_f^{m*})$, $X_f^{m*} > x_f^{m*}$

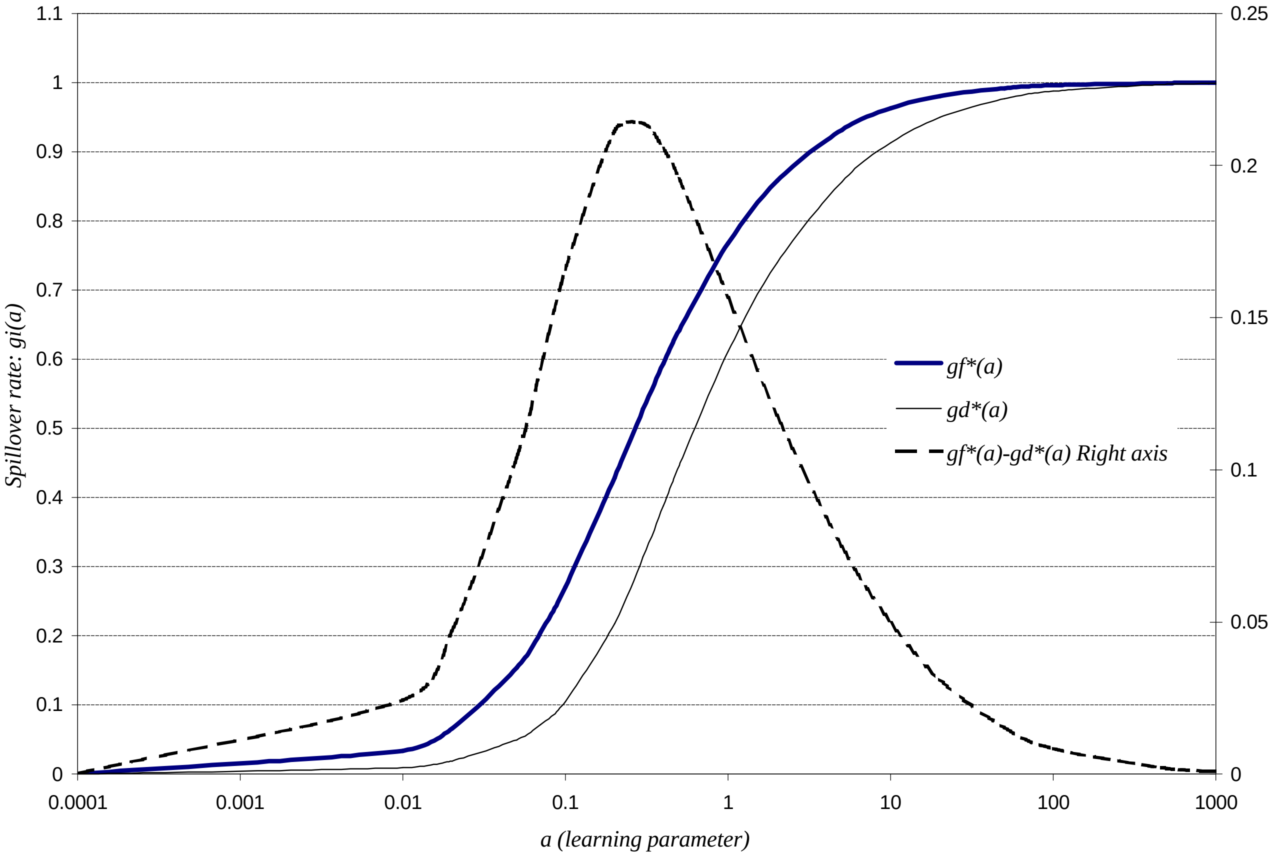
Result 3 is based on the simulations presented in figure Figure 4, showing that the foreign firm's equilibrium R&D investment in the game with absorptive capacity effects is always higher than the corresponding investment level based on the model with exogenous and symmetric spillover rates ($h$), as long as the spillover rate is not 0 or 1.[13] The concave shape of the function representing $X_f^{m*}$ in Figure 4 is a direct result of how the absorptive capacity mechanism in (6) affects the spillover rates that the two firms face.

Notice that in the absorptive capacity mechanism in (6) the positive and decreasing returns to own R&D investments are affected by the size of the learning parameter $a$, as described by the cross derivative:

$$\frac{\partial^2 g_i}{\partial x_i \partial a} = \frac{1 - a x_i}{(1 + a x_i)^3} \tag{15}$$

Here, for any given R&D level, the marginal contribution of R&D to the spillover rate is falling in *a*. A closer look at Figure 1 explains this property more thoroughly. For high R&D levels, more R&D investments will provide a smaller jump in the spillover rate, the larger the learning parameter *a* is (compare the function for different levels of *a*). In other words, at high R&D levels, the slopes of the functions in Figure 1 are reduced as we increase *a*, whereas the opposite is true at low R&D levels. Consequently, when *a* is small, the gains through higher spillover rates from investing more in R&D for the R&D intensive foreign firm are not significantly smaller than for the less R&D intensive domestic firm. Yet, when *a* is large, the gains are much smaller for the foreign firm than for the domestic one.

**Figure 6: Firm specific endogenous spillover rates as a function of *a*.**



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[13] The spillover rate $g_f$*=0 is generated when *a*=0, while $g_f$*=1 is reached when *a* -> ¥. In these cases, the two games become similar and the corresponding R&D investments are equal.

In equilibrium, the relationship between the strength of the absorptive capacity effect - measured in terms of the size of $a$ - and the spillover rates $g_i*$, becomes more complex since a shift in $a$ leads to a change in equilibrium R&D investment $X_i*_,$ which again affects the spillover rates. The forces behind the simulations of equilibrium R&D investment in Figure 4 can best be explained by studying Figure 6, where the subgame perfect equilibrium spillover rates $g_i*$ are described as a function $a$.[14] Notice first that a stronger absorptive capacity effect gives a higher spillover rate for both firms since they are able to learn more from external R&D for a given internal R&D level. However, for any given size of the absorptive capacity effect, firm $f$ experiences a higher spillover rate than the domestic firm since it always has a higher optimal R&D investment level due to the fact that it operates in two markets. This is also illustrated by the dotted curve in Figure 6, representing the absolute difference between the firms' spillover rates $g_f*–g_d*$ (measured on the right vertical axis). When the absorptive capacity effect is small ($a$ close to zero), the higher R&D investment level in firm $f$ has only a small effect on its spillover rate since it is hard to generate absorptive capacity through own R&D, thus the difference in spillover rates is small. Consequently, as presented in Figure 4, the equilibrium R&D investment level is only marginally higher than in the case with exogenous (and equal) spillover rates. As outlined in the previous paragraphs, an increase in the absorptive capacity by scaling up $a$, implies that the positive effect on the spillover rate of more R&D becomes relatively smaller for the foreign firm as compared to the domestic firm. However, as long as $a$ is relatively small, firm $f$ still finds it profitable to raise its R&D investment sufficiently to widen the difference in spillover rates $g_f*–g_d*$ as illustrated in Figure 6. Consequently, the gap between equilibrium R&D investment in the endogenous and exogenous models in Figure 4 is widened as we moderately increase $a$, and thus $g_f*$.

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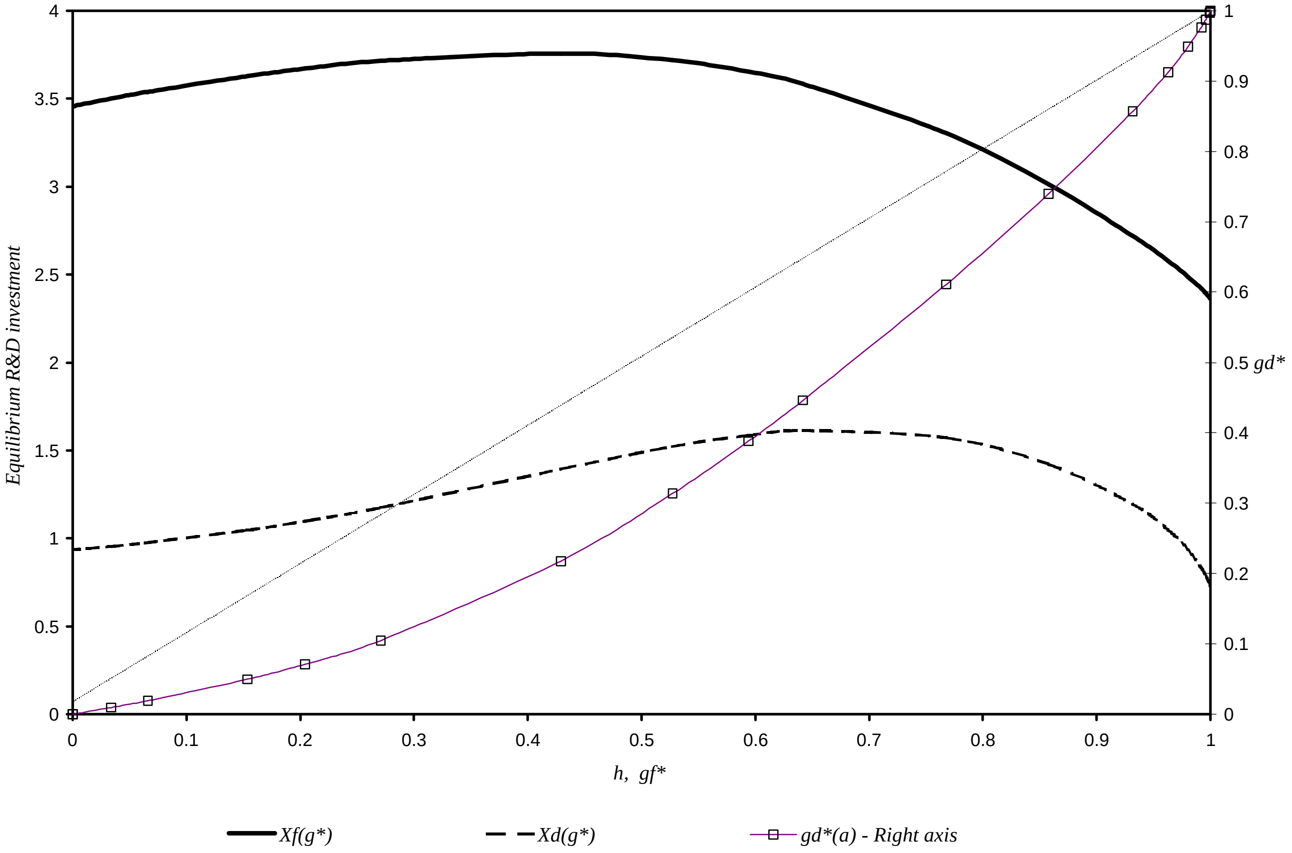
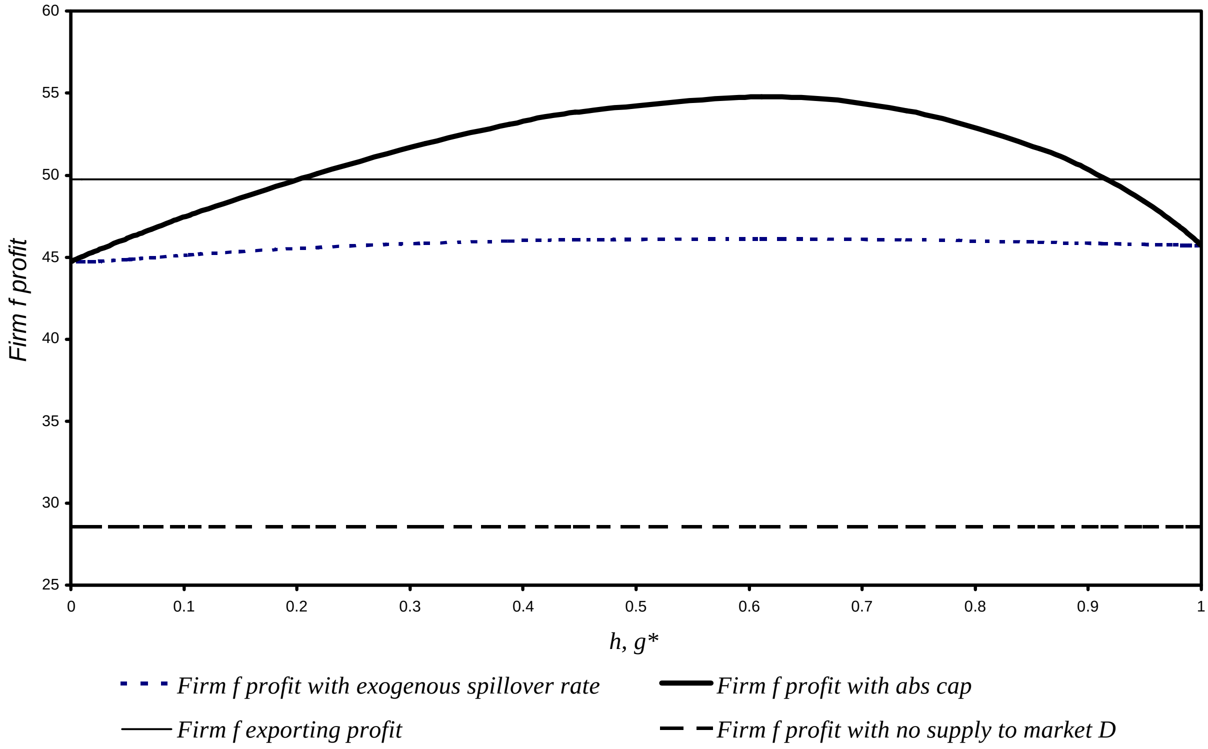
[14] Notice that the scale on the horizontal axis is logarithmic in order to map the effect of a large range of values of the parameter $a$. A linear scale on the vertical axis will provide a relationship between $a$ and the spillover rate $g_i$ with a functional form similar to the one in Figure 1.

**Figure 7: Equilibrium R&D investments of firm *f* and *d* with endogenous spillover rates**



However, above a certain size of the absorptive capacity effect *a*, the foreign firm's marginal contribution of R&D to $g_f$ becomes considerably smaller than for the domestic firm. This drives down firm *f*'s incentive to invest in R&D, whereas it increases the domestic firms incentive to invest. In Figure 7, we depict the equilibrium R&D investment levels of both firms as a function of the endogenous spillover rates. Here, we see that the domestic firm has a growing marginal increase in R&D when the spillover rate is small, which is in line with the description above. Consequently, the difference between the two firms' spillover rates starts to fall and is eventually eliminated when *a* goes to infinity. Thus, as described in Figure 4, firm *f*'s equilibrium R&D investment becomes a falling function in *a* and $g_f$*. Clearly, when *a* becomes large, both firms are able to absorb much of the competitor's R&D, independent of their own R&D investments, implying that both firms confront a large spillover rate $g_i$*. Thus, when the learning parameter *a* grows large, the traditional negative effect of R&D spillovers on R&D investment dominates, reducing the R&D investment of both firms. As a result, the simulation based on endogenous spillover rates provides the same equilibrium R&D investment strategies as the game with exogenous spillovers (*h*) when *a* grows towards infinity. The sensitivity tests presented in Table A1 in Appendix 2 show that the R&D investment pattern described in Figure 4 is maintained for a wide range of values of *b*, yet the larger *b* is, the stronger is the traditional negative effect of R&D spillovers. Consequently, the maximum R&D investment level is obtained for lower spillover rates when the market size is increased. This aspect is discussed in Grünfeld (2001).

**Figure 8: Firm f profit under alternative foreign market entry strategies**



In Figure 8, profit for firm *f* is described under the different strategies regarding how to supply market *D*. Once again, we apply the parameter values used in Section 4, i.e. $b=10$, $G=5$, $t=0$ and the values on the horizontal axis correspond both to the exogenous spillover rate *h* and the endogenous rate $g_f$* as in Figure 4 in order to enable comparisons between the two games. Similar to the mechanism driving equilibrium R&D investment in the game with absorptive capacity effects, profit in this game (the thick full curve) will always exceed the profit obtained in the game without these effects (the thick dotted line). This is due to the fact that firm *f* always gets the advantage of a higher spillover rate in the game with absorptive capacity effects (see Figure 6), whereas the game with exogenous spillover rates ascribes the same spillover rate to both firms.

For small absorptive capacity effects and thus spillover rates, the profit function is increasing in $g_f$* since firm f is able to benefit from an increasing gap between the spillover rates that the two firms face. On the other hand, for strong absorptive capacity effects and thus high spillover rates, the profit function is decreasing in $g_f$* since the gap is narrowed and the traditional negative spillover effect of R&D is strong. The presence of absorptive capacity effects leads us to the following result.

**Result 4:** *The equilibrium entry strategy* $s_f$* *is a function the strength of the absorptive capacity effect (a). Weak and strong absorptive capacity effects favour exports, while medium-sized absorptive capacity effects favour multinationalisation.*

Result 4 describes the trade-off between the absorptive capacity effect and the investment cost associated with going multinational. A weak absorptive capacity effect does not contribute sufficiently to profits in order to compensate for the fixed cost component *G*. This is also the case if the absorptive capacity effect is strong, since the traditional negative spillover effect drives down profits. As opposed to the results in the game with exogenous R&D levels, this game predicts that as spillovers increase, we move from exports to multinationalisation back to exports as the equilibrium entry strategy for firm *f*. The sensitivity tests in Appendix 2 confirm the described profit pattern for alternative foreign market servicing strategies based on varying assumptions regarding the market size. However, shifting *b* implies that the fixed cost *G* associated with going multinational becomes larger or smaller relative to profits. Consequently, as outlined in Table A2 in appendix 2, the simulations may predict that the foreign firm will always go multinational or always export contingent on the relative size of *G* and *b*.

## 6. Conclusion

This paper has explored how R&D spillovers affect the decision to service a foreign market either through exports or going multinational through the establishment of a local subsidiary. We argue that it is important to take into consideration that firms cannot gain from localised R&D spillovers if they do not invest in R&D themselves, a perspective that has come to be named absorptive capacity. The paper presents a game theoretic model where the firms' absorptive capacity makes the rate of spillovers endogenous. In order to properly analyse how the absorptive capacity effect alters the way firms service a foreign market, we must endogenise the R&D investment decision. Thus we present a three-stage Cournot duopoly game where output, R&D investment and the foreign market servicing strategy is endogenised. In the literature there are only a few examples of such models, and none of them includes the absorptive capacity dimension.

The model predicts that a firm will go multinational only if the absorptive capacity effect is not too large or too small. Otherwise the firm will choose to export. The conclusions in the model relate to two opposing effects of the absorptive capacity mechanism. On the one hand, a stronger absorptive capacity effect improves the productivity of R&D investments since learning becomes easier. On the other hand, a strengthening of this effect also improves the competitor's ability to learn, making the well-known negative effect of spillovers on R&D investment larger. This negative effect dominates when the absorptive capacity effect is large, cutting profits from going multinational below the profits derived from exporting. We also show that when absorptive capacity is taken into consideration, firms with a large technology advantage in terms of R&D investments may still find it optimal to go multinational although the gains from learning are small. This is due to the fact that technology leaders have a higher capacity to absorb external R&D results than technology followers.

The idea that technology leaders can be motivated to go multinational in order to gain from localised spillovers is attractive in light of the empirical pattern found among multinationals. That is, multinationals are most often highly R&D intensive and are often regarded as technology leaders. The technological level of these firms provides them with a competitive advantage which gives good reason to enter new markets. However, it is not clear why this entry should be arranged through local presence rather than exports. We claim that one of the reasons may relate to the search for local technological insights that may improve their competitive position further. Such behaviour is often labelled technology sourcing through FDI or multinationalisation.

The ability to absorb local as well as distant knowledge is not only a function of the firm's own R&D activities, but also a function of the publicly available knowledge pool. If a country has a well developed system of universities and public research facilities, the overall absorptive capacity of firms will be enlarged since they more or less freely can draw on this knowledge pool. Thus, a policy with the objective of improving this knowledge infrastructure may have a direct effect on whether foreign firms choose to establish a local subsidiary or supply the country through exports. The results derived in this model predict that such a policy will drive up multinational investment in countries with a weak prior public knowledge infrastructure, while the opposite may be true for countries with a high knowledge level since the absorptive capacity effect then reaches levels where spillovers become detrimental to foreign profits. On the other hand, multinationals may be attracted to such countries since they also may gain from this knowledge pool.

Empirical studies show that the ability to absorb external knowledge is clearly limited by geographical distance. However, investing in R&D may also enlarge the firm's ability to absorb knowledge over larger distances. If we were to take this effect into account, we should also allow endogenous spillovers when firms export. This property is empirically supported by among others Coe and Helpman (1995). Under certain configurations, this could result in a case where spillovers through exports were more profitable than those deriving from going multinational. This is an area which needs further investigation. Also, the welfare effects of absorptive capacity in an international context as well as a more thorough analysis of how the relative size of foreign and domestic market affect the optimal strategy should be studied more thoroughly in the future.

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# Appendix 1: FOCs in the game with absorptive capacity effects and endogenous R&D investments

The first-order condition for firm *f* is:

$$\frac{\partial \Pi_f^m}{\partial X_f^m} = K\left(a, b, X_d^m, X_f^{m*}(a, b, X_d^m)\right) = 0$$

which is given by:

$$\begin{aligned} K(\bullet) = {} & 51baX_f^{m*} + 47baX_d^m - 279a^2X_f^{m*2}X_d^m + 6a^2X_f^{m*}X_d^{m2} + 17b - 47X_f^{m*} - 8X_d^m - 141aX_f^{m*2} \\ & - 20aX_d^{m2} - 84aX_f^{m*}X_d^m + 107ba^2X_f^{m*}X_d^m - 141a^2X_f^{m*3} - 47a^3X_f^{m*4} - 20a^2X_d^{m3} - 8a^3X_d^{m4} \\ & + 17ba^3X_d^{m3} + 17ba^3X_f^{m*3} - 313a^3X_f^{m*3}X_d^m - 87a^3X_f^{m*2}X_d^{m2} - 147a^4X_f^{m*3}X_d^{m2} + 56a^3X_f^{m*}X_d^{m3} \\ & - 110a^4X_f^{m*4}X_d^m - 59a^5X_f^{m*4}X_d^{m2} + 39a^4X_f^{m*2}X_d^{m3} + 13a^5X_f^{m*3}X_d^{m3} + 17a^4X_f^{m*}X_d^{m4} + 51ba^2X_f^{m*2} \\ & + 47ba^2X_d^{m2} + 73ba^3X_f^{m*2}X_d^m + 39ba^4X_f^{m*2}X_d^{m2} + 30ba^4X_f^{m*3}X_d^m + 13ba^5X_f^{m*3}X_d^{m2} \\ & + 17ba^4X_f^{m*}X_d^{m3} + 90ba^3X_f^{m*2}X_d^m = 0 \end{aligned}$$

Similarly, the first order-condition for firm *d* is:

$$\frac{\partial \Pi_d^m}{\partial X_d^m} = L\left(a, b, X_f^m, X_d^{m*}(a, b, X_f^m)\right) = 0$$

given by the following expression:

$$\begin{aligned} L(\bullet) = {} & 5baX_f^m + 6baX_d^{m*} - 12a^2X_f^{m2}X_d^{m*} - 90a^2X_f^mX_d^{m*2} + 2b - 2X_f^m - 14X_d^{m*} - 5aX_f^{m2} \\ & - 42aX_d^{m*2} - 30aX_f^mX_d^{m*} + 11ba^2X_f^mX_d^{m*} - 5a^2X_f^{m3} - 2a^3X_f^{m4} - 42a^2X_d^{m*3} - 14a^3X_d^{m*4} \\ & + 2ba^3X_d^{m*3} + 2ba^3X_f^{m3} + 5a^3X_f^{m3}X_d^{m*} - 42a^3X_f^{m2}X_d^{m*2} + 3a^4X_f^{m3}X_d^{m*2} - 94a^3X_f^mX_d^{m*3} \\ & + 2a^4X_f^{m4}X_d^{m*} - 48a^4X_f^{m2}X_d^{m*3} + a^5X_f^{m3}X_d^{m*3} - 32a^4X_f^mX_d^{m*4} + 5ba^2X_f^{m2} \\ & + 6ba^2X_d^{m*2} + 8ba^3X_f^mX_d^{m*2} + 9ba^3X_f^mX_d^{m*2} + 3ba^4X_f^{m2}X_d^{m*2} + 2ba^4X_f^{m3}X_d^{m*} \\ & + 3ba^4X_f^mX_d^{m*3} + 7ba^3X_f^{m2}X_d^{m*} - 17a^5X_f^{m2}X_d^{m*4} + ba^5X_f^{m2}X_d^{m*3} = 0 \end{aligned}$$

# Appendix 2: Sensitivity analysis

## Table A1:

**Sensitivity analysis:**
**Firm *f* equilibrium R&D investment for different market sizes**

| | ***market size: b*** | | | | | |
|---|---|---|---|---|---|---|
| ***a*** | *0.1* | *1* | *10* | *100* | *1000* | *10000* |
| *0* | *0.03458* | *0.34579* | *3.45794* | *34.5794* | *345.794* | *3457.94* |
| *0.0001* | *0.03458* | *0.3458* | *3.4584* | *34.626* | ***350.06*** | ***3715.4*** |
| *0.01* | *0.03458* | *0.34624* | *3.5006* | ***37.154*** | *330.35* | *2577.3* |
| *0.02* | *0.03459* | *0.34669* | *3.5385* | *37.572* | *301.36* | *2487.3* |
| *0.05* | *0.0346* | *0.34799* | *3.6278* | *35.835* | *271.99* | *2420.7* |
| *0.07* | *0.03461* | *0.34884* | *3.6706* | *34.555* | *264.3* | *2406* |
| *0.1* | *0.03462* | *0.35006* | *3.7154* | *33.035* | *257.73* | *2394.3* |
| *0.2* | *0.03467* | *0.35385* | ***3.7572*** | *30.136* | *248.73* | *2379.7* |
| *0.3* | *0.03471* | *0.35721* | *3.7179* | *28.682* | *245.21* | *2374.5* |
| *0.4* | *0.03476* | *0.36017* | *3.653* | *27.799* | *243.29* | *2371.9* |
| *0.5* | *0.0348* | *0.36278* | *3.5835* | *27.199* | *242.07* | *2370.3* |
| *1* | *0.03501* | *0.37154* | *3.3035* | *25.773* | *239.43* | *2367* |
| *2* | *0.03539* | ***0.37572*** | *3.0136* | *24.873* | *237.97* | *2365.3* |
| *5* | *0.03628* | *0.35835* | *2.7199* | *24.207* | *237.03* | *2364.3* |
| *10* | *0.03715* | *0.33035* | *2.5773* | *23.943* | *236.71* | *2364* |
| *20* | ***0.03757*** | *0.30136* | *2.4873* | *23.797* | *236.53* | *2363.8* |
| *50* | *0.03584* | *0.27199* | *2.4207* | *23.703* | *236.43* | *2363.7* |
| *100* | *0.03304* | *0.25773* | *2.3943* | *23.67* | *236.4* | *2363.7* |
| *500* | *0.0272* | *0.24207* | *2.3703* | *23.463* | *236.37* | *2363.6* |
| *1000* | *0.02595* | *0.23974* | *2.3674* | *23.6364* | *236.37* | *2363.6* |

Figures in bold represent the highest R&D investment level for given market size

# Table A2:

## Sensitivity analysis: Equilibrium entry strategy for firm *f* when *b* is changed

| ***market size b=100 FDI fixed cost G=50*** | | | | ***market size b=1 FDI fixed cost G=0.5*** | | | |
|---|---|---|---|---|---|---|---|
| ***h, gf*(a)*** | ***sf=m exogenous spillover rate*** | ***sf=m endogenous spillover rate*** | ***sf=e*** | ***h, gf*(a)*** | ***sf=m exogenous spillover rate*** | ***sf=m endogenous spillover rate*** | ***sf=e*** |
| *0* | *4924.23* | *4924.23* | *3611.11* | *0* | *-0.00258* | *-0.00258* | *0.36111* |
| *0.0034507* | *4923.90* | *4928.13* | *3611.11* | *3.458E-05* | *-0.00258* | *-0.00257* | *0.36111* |
| *0.2708926* | *4964.62* | *5353.76* | *3611.11* | *0.0034505* | *-0.00261* | *-0.00219* | *0.36111* |
| *0.4290412* | *5010.80* | *5775.06* | *3611.11* | *0.0068861* | *-0.00264* | *-0.00180* | *0.36111* |
| *0.6418017* | *5055.89* | *6456.74* | *3611.11* | *0.0171019* | *-0.00271* | *-0.00062* | *0.36111* |
| *0.707504* | *5061.70* | *6614.35* | *3611.11* | *0.0238367* | *-0.00274* | *0.00017* | *0.36111* |
| *0.767631* | *5062.68* | *6697.79* | *3611.11* | *0.033822* | *-0.00277* | *0.00137* | *0.36111* |
| *0.8576958* | *5055.55* | *6663.23* | *3611.11* | *0.0660926* | *-0.00268* | *0.00542* | *0.36111* |
| *0.8958832* | *5049.18* | *6571.17* | *3611.11* | *0.0967906* | *-0.00240* | *0.00957* | *0.36111* |
| *0.917489* | *5044.66* | *6491.92* | *3611.11* | *0.1259261* | *-0.00199* | *0.01381* | *0.36111* |
| *0.9315045* | *5041.37* | *6427.60* | *3611.11* | *0.1535395* | *-0.00148* | *0.01812* | *0.36111* |
| *0.9626489* | *5033.01* | *6233.83* | *3611.11* | *0.2708926* | *0.00146* | *0.04038* | *0.36111* |
| *0.980294* | *5027.63* | *6073.21* | *3611.11* | *0.4290412* | *0.00608* | *0.08251* | *0.36111* |
| *0.9918056* | *5023.87* | *5926.04* | *3611.11* | *0.6418017* | *0.01059* | *0.15067* | *0.36111* |
| *0.9958408* | *5022.51* | *5858.28* | *3611.11* | *0.767631* | *0.01127* | *0.17478* | *0.36111* |
| *0.9979033* | *5021.80* | *5817.88* | *3611.11* | *0.8576958* | *0.01055* | *0.17132* | *0.36111* |
| *0.9991569* | *5021.37* | *5790.60* | *3611.11* | *0.9315045* | *0.00914* | *0.14776* | *0.36111* |
| *0.9995777* | *5021.22* | *5780.85* | *3611.11* | *0.9626489* | *0.00830* | *0.12838* | *0.36111* |
| *0.9999148* | *5021.10* | *5765.63* | *3611.11* | *0.9918056* | *0.00739* | *0.09760* | *0.36111* |
| *1* | *5021.07* | *5770.75* | *3611.11* | *0.9953867* | *0.00727* | *0.09166* | *0.36111* |