Meet Me Halfway but don't Rush

Absorptive capacity and strategic R&D investment revisited

Leo A. Grünfeld*

NUPI

(Norwegian Institute of International Affairs)

Abstract:
In this paper, we analyse how R&D investment decisions are affected by R&D spillovers between firms, taking into consideration that more R&D investment improves the ability to learn from competing firms - the so-called absorptive capacity effect of R&D. Contrary to earlier studies, we show that absorptive capacity effects of own R&D do not necessarily drive up the incentive to invest in R&D. This only happens when the market size is small or the absorptive capacity effect is weak. Otherwise, firms will actually choose to cut down on R&D. Furthermore, absorptive capacity effects also increase the critical rate of spillovers that determines whether a research joint venture generates more R&D investment than a non-cooperative setting. Finally, we show that strong learning effects of own R&D are not necessarily good for welfare. Moreover, if the market size is large, welfare will be at its highest when the learning effect is small.

Key words: R&D investment, R&D spillovers, absorptive capacity, RJV

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* Corresponding address: NUPI, P. O. Box 8159 Dep, 0033 Oslo, Norway. Tel: +47 22056568
Fax: +47 22177015. E-mail: leoa.grunfeld@nupi.no, URL: www.nupi.no

1. Introduction

The title of this paper is a modification of the title used by Kamien and Zang (2000) where it is emphasised that firms themselves must invest in R&D in order to take advantage of the R&D and innovations generated by others (the absorptive capacity effect). Here, we claim that although this is true, it is only half the story. As pointed out by Cohen and Levinthal (1989), R&D investment both increases a firm's innovative abilities as well as its ability to learn from others. This has two effects on R&D investments in strategic games. On the one hand, it increases the incentive to invest in own R&D. But on the other hand, it gives your competitors a dis-incentive to invest in R&D, implying that there is less to learn from. In contrast to the conclusions of Cohen and Levinthal, we find that a strong absorptive capacity effect of R&D, provides a weaker incentive to invest in R&D. It is only when absorptive capacity is weak or market size is small that firms have a higher equilibrium R&D investment than in the case of no absorptive capacity effects. This is why firms are told to *"meet me halfway but don't rush"*.

Growing empirical evidence indicates that firms that devote a large amount of resources to R&D increase their ability to appropriate the knowledge and technology possessed by other firms.[1] The story behind this mechanism is rather simple. To understand and implement ideas and concepts of others, firms must have the competencies that enable them to understand, decodify and utilise these ideas. Also, to undertake efficient surveillance of external knowledge and technology development, a rigorous understanding of the field of relevant activities is necessary (see Levin et al. (1987)).

[1] See e.g. Cassiman and Veugelers (2003),Cohen and Levinthal (1989) , Griffith et al. (2000) and Jaffe (1986).

The theoretical link between R&D spillovers and the economic behaviour of firms has primarily been analysed within the school of industrial organisation where the framework by d'Aspremont and Jacquemin (1988) (henceforth, AJ) has played a central role. The vast majority of studies that discuss the effect of technology spillovers in this framework assumes that spillovers are a linear function of the opponent's R&D activities.[2] Hence, they do not take into account the idea that spillovers also depend on the R&D activity of the knowledge-absorbing firm. When the rate of R&D spillovers is exogenous, it is assumed that firms learn from external R&D without putting any efforts into the learning process. This is a weak feature, since external R&D comes to the firms as a kind of 'manna from heaven'. It is well known that such models with linearly dependent spillovers predict that an increase in R&D spillovers discourages R&D investment.

In this paper, we develop the AJ model one step further as we bring absorptive capacity into the model, allowing for direct comparisons with the results brought forward by AJ. Recently, the issue of absorptive capacity effects has been raised by a growing number of IO economists, but none of these contributions enable a direct comparison with the AJ model.[3] Cohen and Levinthal (1989) presented a formal model that takes this effect into account. However, the analysis is limited to the first order effects in a two-stage oligopoly game.[4] They conclude that the introduction of absorptive capacity reduces and possibly removes the disincentive effect of R&D spillovers. Kamien and Zang (2000) introduced a 3-stage game where firms first decide upon the R&D approach, implying that firms are able to control the degree of

[2] See e.g., Simpson and Vonortas (1994), Vonortas (1994), De Bondt, Sleuwagen and Veugelers (1988) and Martin (2002). Kamien, Muller and Zang (1992) is another much cited contribution in this literature.
[3] Suzumura (1992) and Simpson and Vonortas (1994) provide comparative statics results based on general cost and demand functions, which implicitly include the case where the firm's own R&D activities affect the firm's absorptive capacity.

knowledge diffusion stemming from its own R&D activities. The authors show that firms may find it optimal to choose a R&D approach that limits the diffusion of knowledge to other firms. Hammerschmidt (1998) presents a model where firms undertake two kinds of R&D investment, one that increases absorptive capacity and one that reduces marginal costs. She shows that although an increase in spillovers reduces the optimal investment in cost-reducing R&D, such an increase may also result in higher investment in the R&D component that is designed to improve the absorptive capacity.

Martin (2002) presents a R&D race model, where the rate of spillovers between firms is endogenised due to the absorptive capacity effect of R&D. The model predicts that the R&D investment behaviour of firms is not significantly different in models with and without absorptive capacity effects. Campisi, Mancuso and Nastasi (2001) present a similar model. They also find that the R&D investment behaviour of firms is not affected by spillovers if R&D drives such spillovers through absorptive capacity effects.

The R&D spillover function in our model enables us to directly compare the results stemming form absorptive capacity effects with the conclusions provided by the AJ model. The model shows that contrary to earlier studies, absorptive capacity effects do not necessarily drive up the incentive to invest in R&D. This only happens when the market size is small or the absorptive capacity effect is weak. Otherwise, firms will chose to cut down on R&D. The analysis in this study differs from many of the earlier studies in that we focus on how the effects of absorptive capacity relate to market size. By changing market size, we show that the conclusions regarding R&D investment and welfare may change.

[4] Cohen and Levinthal (1989) direct the reader to a technical note that shows that the outlined conclusions are also relevant when the full model is analysed using numerical simulations.

Furthermore, when absorptive capacity effects are included, we show that the critical value on the spillover rate that determines whether a research joint venture (RJV) will provide higher R&D investment than the noncooperative equilibrium is higher than in the AJ model. Finally, we show that strong learning effects of own R&D are not necessarily good for welfare. Moreover, if the market is large, welfare will be highest when the learning effect is small.

In Section 2, we present the spillover mechanism that allows for absorptive capacity effects and provide equilibrium R&D investment solutions for the non-cooperative symmetric game. In Section 3 we discuss the impact of absorptive capacity on R&D investment in RJVs. In Section 4, we analyse the welfare implications of absorptive capacity effects in this kind of models. Section 5 concludes and gives some prospects for further research.

2. Absorptive capacity effects in the non-cooperative game

The point of departure in this model is the two stage Cournot duopoly game of Brander and Spencer (1983), upon which AJ is based. Here, firms choose their R&D investment levels x_i $(i=1,2)$ in the first stage, and play a regular Cournot game in outputs q_i in the second stage. In our set-up, we specifically investigate process-enhancing or cost-reducing R&D investments. The subgame prefect equilibrium output and investment levels are identified using backward induction. Firms maximise profits:

(1) $$p_i = \left[p(q_i, q_j) - g_i(x_i, x_j) \right] q_i - u_i(x_i) \quad i = 1,2 \quad i \neq j$$

where p is market price, q_i is firm *i's* output and x_i represents the level of R&D investments. For simplicity, we assume that the market price p is defined by the linear inverse demand function:

(2) $$p = a - q_i - q_j$$

and that unit cost function g has the following form:

(3) $$g_i\left(x_i, x_j\right) = c - x_i - q_i(x_i)x_j \qquad 0 \le q_i(x_i) \le 1$$

where c is the initial unit cost component.[5] The variable q_i describes the proportion of R&D that spills over from firm j to firm i, contributing to a cost reduction. In the AJ approach, this variable is treated as a linear exogenous parameter, $q(x) = g$. Here, it is a function of own R&D investment. We employ a simple quadratic investment cost function:

(4) $$u_i(x_i) = \tfrac{1}{2} x_i^{\,2},$$

which guarantees decreasing returns to R&D and helps to convexify the model. Equations (1) to (4) lead to the well-known expression for the Cournot-Nash equilibrium output levels:

(5) $$q_i^* = \frac{1}{3}\left(a + \left(2 - q_j\right)x_i + \left(2q_i - 1\right)x_j\right)$$

where we assume that $a \equiv a - c > 0$ to ensure positive outputs. In the following discussion, the variable a plays a central role. In the previous literature, the variable has usually been named the *"demand cost margin*. A larger a can either be interpreted as a larger market size or lower marginal costs of production, yet in the following analysis we will focus on market size.[6] We now use (1) to (5) to derive the first-order conditions for optimal R&D investment in the first stage of the game:

(6) $$\frac{\partial p_i}{\partial x_i} = \frac{2}{9}\left(a + (2 - q_j)x_i + (2q_i - 1)x_j\right)\left(2 - q_j + 2x_j \frac{\partial q_i}{\partial x_i}\right) - x_i = 0$$

If we assume that firms are symmetric, the first order condition (6) can be expressed as:

[5] According to Amir (2000), this cost function is associated with a weakness since it may be profitable for one firm to give a R&D dollar to the competitor, instead of investing itself. However, since the model is symmetric, the Amir critique will not apply here.
[6] This is also the interpretation suggested by Martin (2001), since a represents the quanity that would be demanded if price were equal to marginal cost.

$$\text{(7)} \qquad \frac{\partial p}{\partial x} = 4(1+q)\frac{\partial q}{\partial x}x^2 + \left(4a\frac{\partial q}{\partial x} + 2(2-q)(1+q) - 9\right)x + 2a(2-q) = 0$$

(7) allows us to compare the equilibrium R&D investment level in a game where the spillover rate is affected by absorptive capacity effects (*q(x))* to the AJ game where the spillover rate is exogenous (*g):*

Proposition 1: *If the exogenous spillover rate (g) in the AJ game is the same as the spillover rate (q) generated by the game with absorptive capacity effects, equilibrium R&D investment in the absorptive capacity game will always be higher than in the AJ game.*

Proof of Proposition 1: Let $\bar{x}$ represent equilibrium R&D investment when we have absorptive capacity effects, and $\hat{x}$ be the equilibrium R&D investment when no such effects are present.

Furthermore, define

$$A = 4(1+q)\frac{\partial q}{\partial x} > 0,\ \ \mathrm{B} = 4a\frac{\partial q}{\partial x} > 0,\ \ \mathrm{C} = 9 - 2(2-q)(1+q) > 0,\ \ \mathrm{D} = 2a(2-q) > 0$$

in the first-order condition in (7). Then, we know from (7) that $-A\bar{x}^2 + (C-B)\bar{x} = D$ and $C\hat{x} = D$ since $g = q$ and $\partial q / \partial x = 0$ in the case without absorptive capacity effects. Thus, $-A\bar{x}^2 + (C-B)\bar{x} = D = C\hat{x}$. If equilibrium R&D in the game with absorptive capacity effects is to be smaller than in the AJ case, we must have that $\bar{x} < \hat{x}$. For this to be the case, the following condition: $C\hat{x} - C\bar{x} = -A\bar{x}^2 - B\bar{x} > 0$ must be satisfied. But this is not possible for non-negative R&D investment levels.

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Proposition 1 shows that spillovers work differently in the absorptive capacity model than in the AJ model. Although we compare two games based on the exactly same spillover rate, we still get higher R&D in the absorptive capacity game. This extra equilibrium R&D investment stems from what we call the "***positive learning effect***". It simply states that if we separate out the ***negative traditional effect of spillovers*** on R&D investment in the model with absorptive capacity, we are left with a pure learning effect of own R&D that drives up the incentive to invest in R&D.

In order to compare equilibrium R&D investments and output when *q(x)* differs from *g*, we need to introduce a specific absorptive capacity function. First, we wish to satisfy the condition stating that $0 \leq q \leq 1$. 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.[7] A simple functional form that satisfies these two requirements is given by:

(8) $$q(g,x,s) = \frac{g + sx}{1 + sx} \qquad 0 \leq g \leq 1, \quad s \geq 0, \quad x > 0$$

where g is the exogenous spillover rate used in the AJ model. The parameter s is a scaling parameter that adjusts the size of $\partial q / \partial x$.[8] In other words, s is a ***learning parameter*** that represents the efficiency of own R&D in promoting absorptive capacity.[9] First, observe that the absorptive capacity function in (8) has the following limit properties:

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[7] In other words, the marginal increase in the ability to learn from the R&D undertaken by the competitor is larger when you invest one more dollar at a low R&D level compared with one more dollar invested at a high R&D level. A possibly more realistic learning function is based on the logistic learning curve, see Kashenas and Stoneman (1995). However, such a specification would vastly complicate the derivation of strategic responses in the game.

[8] If $s=0$, we are back to the traditional exogenous spillover mechanism used in AJ where R&D spillovers enter the firms' cost function as 'manna from heaven'. If both s and g are set equal to zero, there are no spillovers at all, hence, we are back to the Brander and Spencer (1983) model. This absorptive capacity function is similar to the one in Martin (2002). However, the exogenous spillover rate g is not an integral part of the function in his model.

[9] Cohen and Levinthal (1989) apply a related procedure where their parameter β describes the characteristics of outside knowledge that make 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.

$$\lim_{x\to\infty} q(g, x, s) = 1 \quad \text{and} \quad \lim_{x\to 0} q(g, x, s) = g$$

Hence, the absorptive capacity function satisfies the outlined restrictions on spillovers. Furthermore, if the exogenous spillover parameter g is set to zero, the specification allows no 'manna from heaven', i.e. a firm that does not invest in R&D has no ability to learn from external R&D.[10] If g =1, there is no opening for further increases in the spillover rate through own R&D investment, and the function q takes the value 1 for any level of R&D investment. Combining the first order condition (7) with the absorptive capacity function (8) yields:

(9) $$\frac{\partial p}{\partial x} = \frac{2}{9}\left(a(1+sx)+x(1+g+2sx)\right)\left(2-\frac{g+sx}{1+sx}+2x\frac{s(1-g)}{(1+sx)^2}\right)-x(1+sx)=0$$

In the case with no absorptive capacity effects (*s=0)* as in the AJ model, we have that $q = g$ and $\partial q/\partial x = 0$. Then, (9) can be expressed by the explicit and unique solution:

(10) $$x^* = \frac{2a(2-g)}{9-2(2-g)(1+g)}$$

As shown in AJ, a larger market size (*a*) gives a stronger incentive to invest in R&D, independent of the size of the spillover parameter. The gains from investing in R&D are increasing in *a* since the cost reducing effect of R&D affects a larger volume of sales in the second stage of the game, driving up profits. It is straightforward to show that a higher spillover rate in (10) leads to lower equilibrium R&D investment.

Rearranging (9) provides us with the following fourth order polynomial in R&D investment, under the assumption that there is no 'manna from heaven' (*g=0*):[11]

(11) $$\frac{\partial p}{\partial x} = a\left(4+14sx^*+12s^2x^{*2}+2s^3x^{*3}\right)-5x^*-9sx^{*2}-5s^2x^{*3}-5s^3x^{*4}=0$$

[10] This aspect is also discussed by Kamien and Zang (2000).
[11] The case with 'manna from heaven' is discussed later in this section.

The equilibrium R&D investment level based on the absorptive capacity function (8) becomes an implicit function of the market size (a) and the learning parameter (s). Thus we can study the equilibrium R&D level as a function of these variables alone. There is no easily interpretable explicit solution to the equilibrium R&D investment in (14), yet it is possible to analyse the behaviour for all combinations of a and m using numerical simulations.[12,13]

INSERT FIGURE 1 HERE

In Figure 1, we simulate the equilibrium R&D investment in 4 different games. The thick full line represents game 1 where the absorptive capacity effect $s=1$. Game 2 is represented by the thin and linear curve, and is the Brander and Spencer model with no spillovers at all, where firms over-invest in R&D. The thin dotted line represents game 3, which is the AJ model given by (10) with a spillover rate $g=0.5$.[14] Finally, in game 4, which corresponds to the thick dotted line, we translate the spillovers generated by the absorptive capacity game ($s=1$) into exogenous spillover rates. This is equivalent to the exercise in Proposition 1. In mathematical terms we set:

$$g = q^* = \frac{sx^*}{1+sx^*}$$

In words, in game 4 we study how x in the AJ model compares to our model, using the same spillover rate. This spillover rate q^* varies with the size of a, and is represented by the marked line that converges to 1 as a grows (see the right vertical axis). Thus, the generated spillover rate applies to both the game 1 and game 4.

[12] The expression in (14) has four solutions: two of them have complex roots, one is always negative and one is always positive. We focus on the real and non-negative solution.
[13] The second order condition for local maximum is given by

$$a(14s+24s^2x+6s^3x^2)-5-18sx-15s^2x^2-20s^3x^3<0$$

and is satisfied for all parameter combinations represented in Table 1. Also, the Tatônnement requirement for local stability (see Vives (1999)) is satisfied for all parameter combinations.
[14] The reason why we present this game is that the AJ model predicts that firms will neither under-invest nor over-invest in R&D with this spillover rate.

The simulations in Figure 1 verify Propostion 1 as R&D investment in game 1 is always higher than in game 4. We also see that the *positive learning effect* (the difference in R&D investment between game 1 and game 4 is growing in *a* but that the marginal contribution of *a* is decreasing. Notice that when we compare the equilibrium R&D investment level in the absorptive capacity model with the AJ model, it is the interplay between the *positive learning effect* and the *negative traditional effect of spillovers* that drives the conclusions.

INSERT TABLE 1 HERE

For values of *a* larger than *a'* in Figure 1, R&D investment is lower in the game with absorptive capacity effects than the game without spillovers. At even higher values of *a*, R&D investment in the absorptive capacity game actually also undercuts the investment level generated by the AJ model, with a spillover rate *g=0.5*. In Table 1, we calculate the equilibrium R&D investment as a function of *a* and s, spanning out the range of *s* from 0.1 to 1 billion in order to ensure that the patterns depicted in Figure 1 are representative for all possible values of the learning parameter s. The shaded area in Table 1 represents all those combinations of *a* and *s* where R&D investment is lower in the absorptive capacity game (game 1) than in the game with no spillovers at all (game 2). The lightly shaded area represents the cases where R&D investment is also lower than in the AJ model (game 3). The reported figures show that as the learning parameter *(s)* increases, the critical size of *a=a'* unambiguously falls. This pattern is valid for all values of the learning parameter *a* and provides us with the following results:

Result 1: *For a sufficiently large market size (a>a'), equilibrium R&D investment is lower in the absorptive capacity game (no manna from heaven) than in the game with no spillovers. For an even larger market size, R&D investment in the absorptive* *capacity game will also fall below the R&D investment generated in the AJ game with any exogenous spillover rate.*

The mechanism driving Result 1 is directly linked to the findings in Proposition 1 where we separate the *positive learning effect* from the *negative traditional spillover effect* on R&D investment in the absorptive capacity model. From (10), we know that for any exogenously given spillover rate *g* in the AJ model, there is a positive and linear relationship between the size of the market (*a*) and the strength of the *negative traditional effect of spillovers* on R&D investment.[15] Although the *positive learning effect* also grows with the size of *a*, the growth rate is decreasing. This is due to the way we model the absorptive capacity mechanism in (8). A larger market size drives up equilibrium R&D investment, but as equilibrium R&D investment increases, due to a higher *a*, the marginal capacity to absorb external R&D falls. Therefore, the increase in the positive learning effect of own R&D is falling with the size of *a*. Consequently, at a sufficiently large market size ($a>a'$), the negative traditional effect of spillovers outweighs the positive learning effect, driving equilibrium R&D investment in the game with absorptive capacity effects below R&D investment in the game with no spillovers.

INSERT FIGURE 2 HERE

The impact of changing the learning parameter *s* on equilibrium R&D investment is illustrated in Figure 2. Here, we describe the same exercise as in Table 1, but for expositional purposes, we only report for a selection of values of *s*. The thick marked line in Figure 2 is once again the Brander and Spencer game where $s=0$ (no spillovers). The patterns in Figure 2 and Table 1 provide the following result:

[15] This effect is best illustrated by the increasing gap between equilibrium R&D investment in the game with no spillovers and the AJ game with $g=0.5$, as *a* grows in Figure 1.

Result 2: *If the learning parameter s is increased, the critical size of the market (a') falls. This implies that the range of the market size for which R&D investment is lower in the absorptive capacity game than the game without spillovers is widened.*

The intuition behind Result 2 can also be related to the spillover mechanism in (8). When the learning parameter *s* is increased, the *positive learning effect* is also strengthened. However, a higher value of *s* also drives up the *negative traditional spillover effect* since the spillover rate *q* grows. If we now increase the size of the market, the relative importance of the negative traditional spillover effect is enlarged, driving down the equilibrium R&D investment level. Consequently, the critical level *a'* is reduced as the learning parameter *s* is increased. The positive learning effect dominates when *(a)* is small, implying that a large *s* generates the highest equilibrium R&D investment level. But in larger markets, the *negative traditional spillover effect* is magnified by *s*, driving down R&D investment.[16]

Notice that with a sufficiently small *a* (*a*<*a'*), the absorptive capacity game generates higher R&D investment than a game with no spillovers. Thus, our model predicts that spillovers may give an extra incentive to invest in R&D. This result contrasts the earlier theoretical literature on spillovers where it is claimed that spillovers have an unambiguous negative incentive effect on R&D investment.

Both endogenous and exogenous spillover rates

We now turn to the case where there exist both R&D spillovers that depend on the absorptive capacity of the firms and exogenous spillovers, i.e. $\gamma>0$. In other words, there is 'manna from heaven' in the model. Why should one be concerned with such a case?

[16] In Figure 2, it looks like the line representing *s=0.1* always stays above the line representing the case without absorptive capacity effects, but this is not correct (see Table 1). If we extend the graphs along the horizontal axis, the thin dotted line will eventually fall below the thick marked line.

It is possible to claim that a proportion of the R&D results or knowledge that is generated within an industry is widely understood by the general public. Thus, rival firms do not need to invest further in absorptive capacity in order to take advantage of this knowledge.

When we also allow exogenous R&D spillovers in the model, the first-order condition for optimal R&D investment becomes more complex:

(12)
$$a\left(4+14x^{*}+12x^{*2}+2x^{*3}-8gx^{*}-6gx^{*2}-2g\right) -5x^{*}-9x^{*2}-5x^{*3}-5x^{*4}+2gx^{*}-10gx^{*3}-6g^{2}x^{*2}-2q^{2}x^{*}=0$$

In (12) we have set *s=1*, and the effect of changing *g* is illustrated in Figure 3. A higher *g* value contributes to lower R&D investment, just as described in the AJ model . This illustrates that the introduction of exogenous R&D spillovers only works through the *traditional negative spillover effect on R&D investment* as in AJ. Hence, when the games include 'manna from heaven', the critical value of *a=a'* is unambiguously reduced since the negative spillover effect on R&D investment out-competes the positive learning effect of own R&D at a smaller market size. This leads us to the following result:

Result 3: *In a game with both absorptive capacity effects and spillovers independent of own R&D investment ('manna from heaven'),* γ>0, *the critical value a' falls as g rises.*

INSERT FIGURE 3 HERE

3. Optimal R&D investment in research joint ventures.

A well-known property of the Brander Spencer model is the so-called over-investment effect whenever there are no spillovers present in the industry. Since firms have to pre-commit to the R&D investment level before the second stage, they are forced into a prisoner's dilemma situation where over-investment in R&D becomes the best response.

As shown in AJ, the over-investment effect is not necessarily valid in a game with R&D spillovers since spillovers force down the equilibrium R&D investment level. When firms join together in a research joint venture (RJV), but compete against each other in the output market, firms internalise the external effect of R&D. Hence, the optimal R&D investment level in a RJV is consistent with cost minimisation for any given output level, see Brander and Spencer (1983). The RJV seeks to maximize the sum of profits with respect to R&D investment:

(13) $$\max_{x_i, x_j} (\pi_i + \pi_j) = \max_{x_i, x_j} \Pi = q_i^2 + q_j^2 - u(x_i) - u(x_j)$$

Similarly, minimizing costs with respect to R&D investment for a given output level gives the following condition:

(14) $$\frac{\partial c_i}{\partial x_i} q_i + \frac{\partial u_i}{\partial x_i} = 0$$

Since the second-order condition for the optimisation problems in (14) implies: $\partial^2 c_i / \partial x_i^2 + \partial^2 u_i / \partial x_i^2 \geq 0$, a firm will be under (over) investing in the non-cooperative equilibrium if the expression on the left hand side of (14) is negative (positive). This is so since an increase in investment will cut unit costs more than it contributes to increase investment costs.

Using the profit function (1) and the cost and demand structures defined in (2) – (4) as well as the assumption of symmetry, condition (14) specified in the non-cooperative case with no absorptive capacity ($s=0$) gives the following expression:

(18) $$\frac{\partial c_i}{\partial x_i} q_i + \frac{\partial u_i}{\partial x_i} = \frac{\partial \pi_i}{\partial q_j} \frac{\partial q_j}{\partial x_i} q_i = \frac{1}{3} q(1 - 2g)$$

where q is non-negative. This provides us with the well known result from the AJ model with exogenous spillovers, stating that firms will under-invest in R&D as long as the spillover rate is higher than g^{**}=0.5. If it is lower than 0.5, firms will over-invest in

R&D. Next, we analyse the same criteria in the case with absorptive capacity effects, but with no manna from heaven ($g=0$).

(19) $$\frac{¶\, c_i}{¶\, x_i} q_i + \frac{¶\, u_i}{¶\, x_i} = \frac{¶ p_i}{¶\, q_j} \frac{¶\, q_j}{¶\, x_i} q_i = \frac{1}{3} q \left(\frac{1 + sx(1 - sx)}{(1 + sx)^2} \right)$$

Since $(1+sx)^2$ is always positive, the critical spillover value q^{**} for whether firms over- or under-invest depends on the sign of $(1+sx(1-sx))$. Solving this expression with respect to sx gives the following condition for when the sign shifts:

(20) $$sx = \frac{1+\sqrt{5}}{2} \qquad \Rightarrow \qquad q^{**}(s, x,\ g = 0) = \frac{1+\sqrt{5}}{3+\sqrt{5}} \approx 0{,}618$$

This gives a clear interpretation of the consequence of implementing absorptive capacity effects in the AJ model.

Proposition 2: *The critical rate of spillovers (q^{**}) at which equilibrium R&D investment is the same in the RJV game as in the non-cooperative game, is higher when we take into consideration the absorptive capacity effect of R&D compared with the case with exogenous R&D spillover rates.*

Proof: The proposition is based on the direct comparison of (19) and (20).

The logic behind Proposition 2 relates directly to Proposition 1 and the findings in Figure 1. Since firms in the game with absorptive capacity effects always invest more than in the game without such effects, given the same R&D spillover rate ($g=q^*$), we know that the investment level with absorptive capacity effects will be higher when $q^*=g=0.5$. Thus, the introduction of absorptive capacity effects increases the range of spillover rates where firms over-invest in R&D. This result is independent of the size of s and a.

4. The welfare effects of absorptive capacity

To assess how welfare is affected by the introduction of absorptive capacity effects in Cournot duopolies, we need to take into consideration both firms' profit as well as consumer surplus. Using the symmetry assumption and the linear inverse demand function in (7), consumer surplus is given by:

(21) $$S(q) = \frac{1}{2}\left(p(0) - p(2q^*)\right)2q^* = 2q^{*2}$$

Thus, welfare is simply given by:

(22) $$W = 2p + S(q) = 4q^{*2} - x^{*2}$$

INSERT TABLE 2 HERE

In Table 2 we report the results from numeric simulations for welfare under alternative market sizes (a) and absorptive capacity effects (s) given by (22). Using (5) and the symmetry condition, (22) can be written as:

(23) $$W = \frac{4}{9}\left(a + \left(1 + \frac{sx^*}{1 + sx^*}\right)x^*\right)^2 - x^{*2}$$

where x* is the equilibrium R&D level taken from the simulations of (11). The shaded observations in Table 2 represent the value on the learning parameter $s = s^w(a)$ that provide the highest welfare outcome for alternative market sizes. It is important to notice that in contrast to the AJ model, there is no unique R&D spillover rate that maximises welfare in the game with absorptive capacity effects. The simulations provide the following result:

Result 4: *When we include absorptive capacity effects in the Cournot duopoly model, the relationship between welfare and absorptive capacity becomes a function of the market size. The highest welfare in a small market is reached when the absorptive capacity effect of R&D (s) is large, while welfare is highest in a large market when the absorptive capacity effect of R&D is small.*

The intuition behind Result 4 is strongly related to the findings in Figure 1. We know from Section 2, that when the market size (*a*) is small, the positive learning effect of R&D has a relatively strong impact on R&D investment compared with the negative traditional spillover effect. If welfare is improved through higher R&D investment and output, then welfare will be high if the value of the learning parameter (*s*) generates high equilibrium R&D investment. In Figure 2, we see that as the market size grows, the value of the learning parameter that provides the highest R&D investment is falling, explaining the welfare results in Table 2.

Furthermore, according to our numerical simulations, the welfare level will never be lower in the model with absorptive capacity effects ($s>0$) than in the model without spillovers ($s=0$). This result mimics the result based on the AJ model. The logic relates directly to how R&D spillovers affect equilibrium output. In the AJ model, the highest output is reached when the R&D spillover rate $g=0.5$, and the equilibrium output declines symmetrically around this point.[17] Similarly, since the absorptive capacity mechanism generates spillovers in the model, it is only when s=¥ that output gets as low as when $s=0$.

Result 5: *For any market size (a), welfare will always be higher when firms have an absorptive capacity as compared to the case with no spillovers.*

[17] This can be found by maximising output with respect to the R&D spillover rate.

Result 5 is based on the simulations in Table 2 and highlights the importance of the positive learning effect of absorptive capacity.

5. Conclusions and prospects for further research.

The main message of this paper is that results derived from the study of optimal R&D investment with R&D spillovers depend strongly on how we model the R&D spillover mechanism. More specifically, it is shown that if we treat the absorptive capacity of firms as a function of their own R&D activity, the question of whether equilibrium R&D investment will increase or decrease compared with the case with exogenous R&D spillovers is a question of market size. If the market is small, the absorptive capacity effect will drive up R&D investment, while the opposite is true when the market is large.

We explain this result through two opposing effects of absorptive capacity generated through own R&D investment. The first effect works similar to the traditional negative spillover effect on R&D outlined in the previous literature. It states that including the absorptive capacity effect increases the spillover rate in a symmetric R&D game, which unambiguously drives down R&D investment. The other effect, which we call the positive learning effect of own R&D investment, relates to the positive impact of absorptive capacity on the firms own cost function. We show that the same spillover rate in a game with absorptive capacity effects always provides higher R&D investment compared with a game without such effects.

Our conclusions imply that the previously outlined relationship between R&D spillovers and R&D investment is altered when we allow for absorptive capacity effects. Furthermore, the predictions of Cohen and Levinthal (1989) where absorptive capacity effects unambiguously increases the incentive to invest in R&D, is called into question by this study.

The conclusions from this analysis also add new insight into the theory of research joint ventures (RJVs). We show that the introduction of a RJV will force up R&D investments in fewer cases when we allow for absorptive capacity effects. *Ceteris paribus*, this finding gives less support to policies that promote RJVs, since the social problem of under-investment in R&D may be smaller than indicated by previous theoretical literature.

Finally, the model shows that strong learning effects of own R&D are not necessarily good for welfare. Moreover, if the market is large, welfare will be at its highest when the learning effect is small. However, we find that welfare will always be higher in a model with absorptive capacity than in a model with no spillovers at all.

There is reason to expect that public investment in R&D through the public education and university system, as well as through public research institutions, may improve the absorptive capacity of firms since such investments provide a knowledge system that is broad based and available to many firms at a low cost. In this respect, the model presented in this paper suggests that public policy should be aimed at improving the absorptive capacity of firms if they operate in a relatively small market or country. The larger the market is, the stronger will the negative effect of R&D spillovers on R&D investment be, and this effect may actually reduce welfare if the absorptive capacity is increased. This effect contrasts the policy advice provided by Martin (2002) where the promotion of absorptive capacity always improves welfare.

Naturally, the effects described in this model do not represent the full story on how firms determine their R&D investments. The model predicts for instance that firms operating in a large market with high absorptive capacity, will choose to invest less in

R&D. This contrasts the results derived from models with scale-economies (see e.g. Romer (1986)), which predict that R&D investments will be higher in large markets due to positive externalities. But the model may still sheds light on some mechanisms that may play a role in the decision of firms with respect to R&D investment and strategic market behaviour.

The conclusions derived in this paper are solely based on the assumption of symmetric firms. In the real world, firms are equipped with vastly different technologies and abilities to learn from external knowledge. Thus, future research should focus on the impact of absorptive capacity effects in asymmetric games, where the outlined effects may be modified.

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Figures

Figure 1: Equilibrium R&D investment in 4 different games

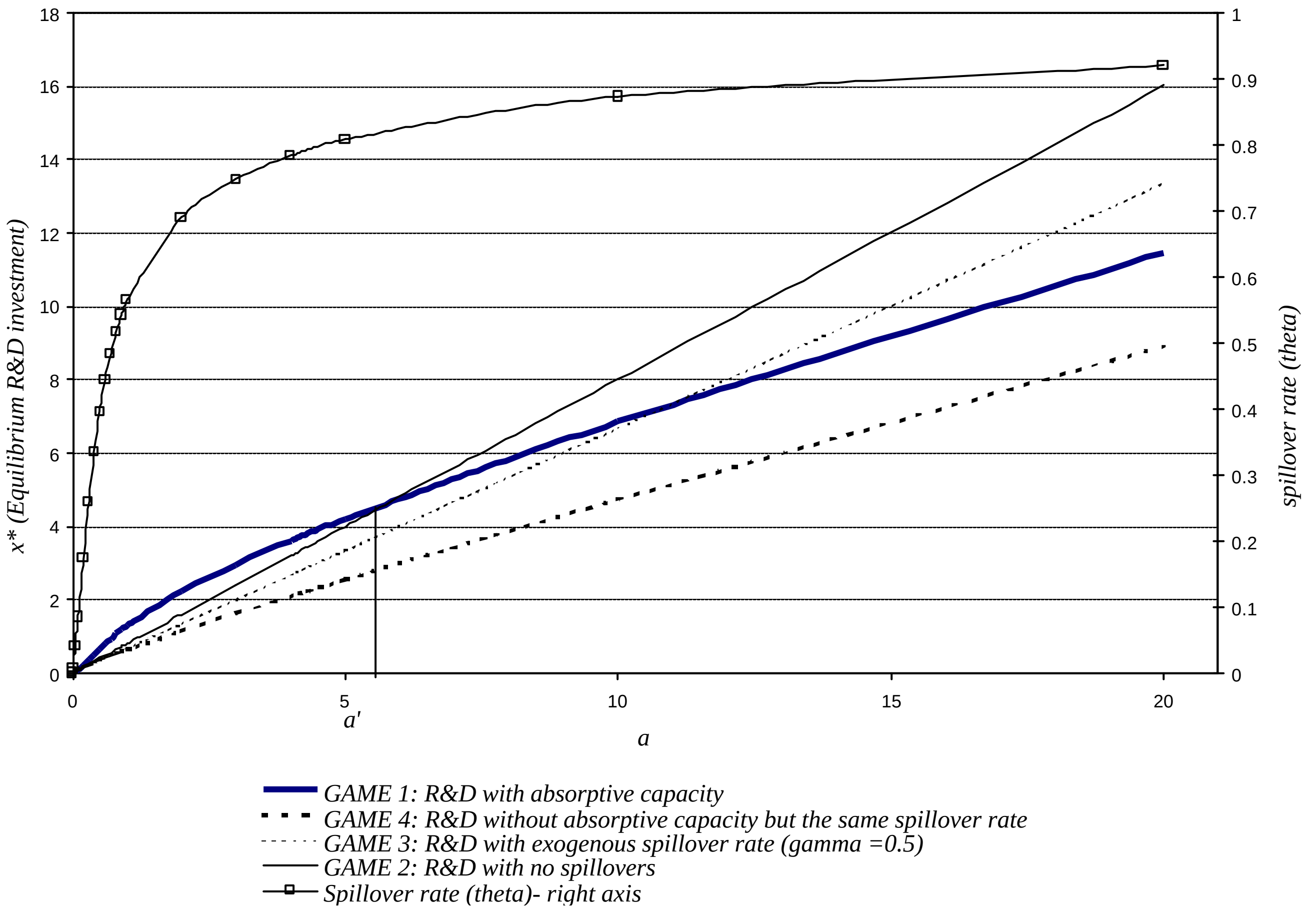


Figure 2: Equilibrium R&D investment for varying learning parameter values

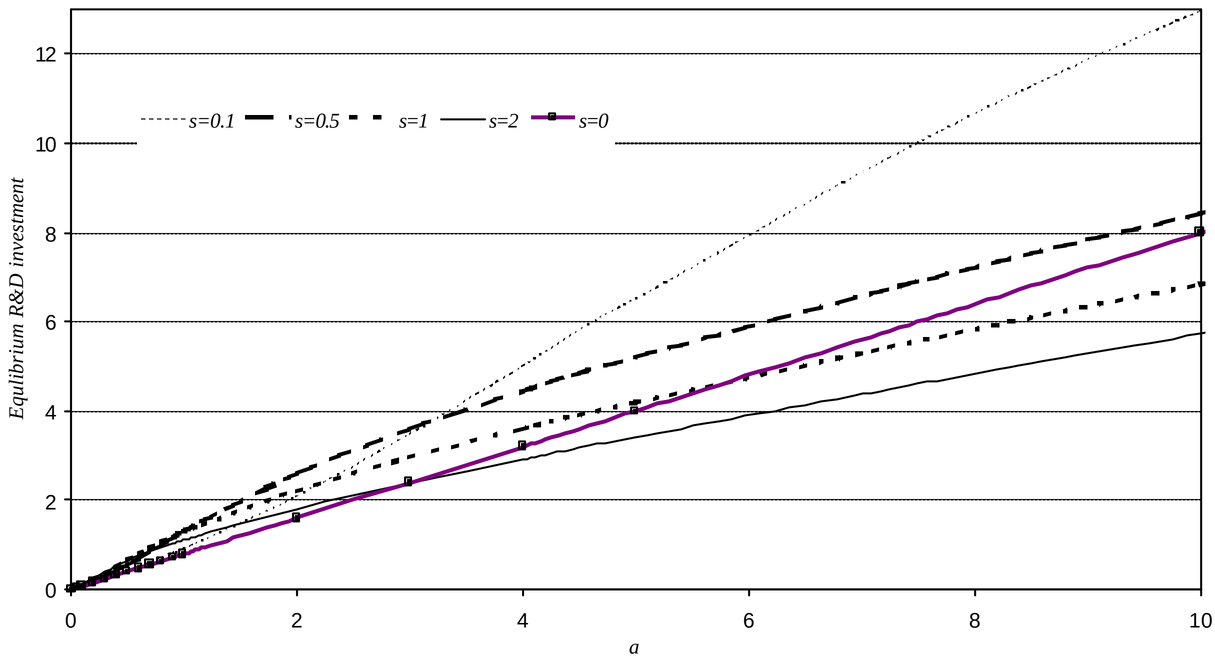
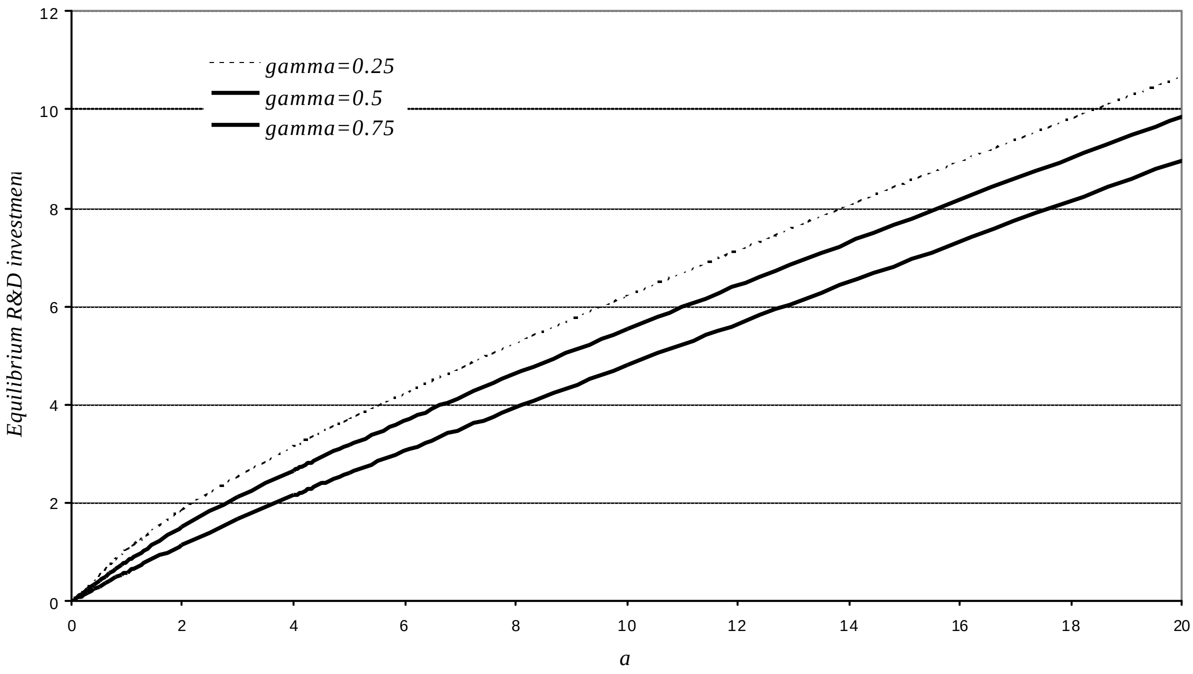


Figure 3: Equilibrium R&D investment in the game with absorptive capacity (s=*1*) and varying degrees of 'manna from heaven'



Tables

Table 1: Equilibrium R&D as a function of market size (*a*) and absorptive capacity (*s*)

a	*s=0*	*s=0*	*s=0.1*	*s=0.5*	*s=1*	*s=2*	*s=10*	*s=1000*	*s=1bn*
	g *0*	*0.5*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
	No spillovers	*Manna from heaven'*							
0.0001	0.00008	0.000067	0.00008	0.00008	0.00008	0.00008	0.0000801	0.0000917	**4.001E-05**
0.001	0.0008	0.00066	0.000801	0.000801	0.000801	0.0008	0.000811	0.000817	**0.0004**
0.01	0.008	0.0066	0.008	0.00805	0.0081	0.00822	0.00917	**0.00684**	**0.004**
0.05	0.04	0.0333	0.0402	0.04139	0.0428	0.04587	0.0653	**0.02413**	**0.02**
0.1	0.08	0.0666	0.081	0.0856	0.0917	0.10543	0.1297	**0.04449**	**0.04**
0.2	0.16	0.1333	0.1644	0.18349	0.209	0.25067	0.222	**0.084722**	**0.08**
0.3	0.24	0.2	0.25	0.2943	0.349	0.39925	0.296	**0.12481**	**0.12**
0.4	0.32	0.266666	0.338	0.4181	0.501	0.5315	0.361	**0.16485**	**0.16**
0.5	0.4	0.33333	0.428	0.5537	0.655	0.6488	0.42	**0.2048**	**0.2**
0.6	0.48	0.4	0.5211	0.6985	0.798	0.7548	**0.477**	**0.2449**	**0.24**
0.7	0.56	0.4666	0.616	0.8493	0.934	0.8525	**0.5316**	**0.28491**	**0.28**
0.8	0.64	0.5333	0.714	1.0027	1.063	0.9438	**0.584**	**0.3249**	**0.32**
0.9	0.72	0.6	0.814	1.1558	1.1836	1.03	**0.634**	**0.3649**	**0.36**
1	0.8	0.6666	0.917	1.3066	1.2976	1.1121	**0.6884**	**0.4049**	**0.4**
2	1.6	1.33333	2.09	2.5952	2.22	1.8053	**1.1461**	**0.8049**	**0.8**
3	2.4	2	3.49	3.5956	2.96	**2.3877**	**1.5786**	**1.205**	**1.2**
4	3.2	2.6666	5.01	4.4483	3.61	**2.9197**	**1.999**	**1.605**	**1.6**
5	4	3.3333	6.53	5.2138	4.196	**3.4223**	**2.4138**	**2.005**	**2**
10	8	6.66666	12.97	8.4199	**6.84**	**5.7303**	**4.4495**	**4.005**	**4**
20	16	13.3333	22.24	**13.689**	**11.462**	**9.9966**	**8.4722**	**8.005**	**8**
50	40	33.3333	42.099	**27.288**	**24.138**	**22.248**	**20.488**	**20.005**	**20**
100	80	66.6666	**68.447**	**48.276**	**44.49**	**42.361**	**40.494**	**40.004**	**40**
10000	8000	6666.6666	**4049.4**	**4010**	**4005**	**4002.5**	**4000.5**	**4000**	**4000**

Table 2: Welfare as a function of market size (*a*) and absorptive capacity (*s*)

a	s=0	s=0	s=0.1	s=0.5	s=1	s=2	s=10	s=1000	s=1bn
	g 0.5	0	0	0	0	0	0	0	0
	Manna from heaven								
0.0001	1.3378E-08	8.00E-09	8.0001E-09	8E-09	8E-09	8E-09	8.01E-09	9.26E-09	1.28E-08
0.001	1.3244E-06	8.00E-07	8.001E-07	8.01E-07	8.01E-07	8.02E-07	8.1E-07	1.45E-06	1.28E-06
0.01	1.3244E-04	8.00E-05	8.0102E-05	8.05E-05	8.1E-05	8.21E-05	9.26E-05	0.000184	0.000128
0.05	0.0033	0.0020	0.0020	0.0021	0.0021	0.0023	0.0046	0.0036	0.0032
0.1	0.0133	0.0080	0.0081	0.0086	0.0093	0.0111	0.0240	0.0137	0.0128
0.2	0.0533	0.0320	0.0329	0.0371	0.0444	0.0641	0.0977	0.0532	0.0512
0.3	0.1200	0.0720	0.0749	0.0909	0.1211	0.1821	0.2092	0.1182	0.1152
0.4	0.2133	0.1280	0.1351	0.1775	0.2562	0.3632	0.3538	0.2088	0.2048
0.5	0.3333	0.2000	0.2142	0.3057	0.4599	0.5995	0.5283	0.3250	0.3200
0.6	0.4800	0.2880	0.3131	0.4847	0.7277	0.8844	0.7346	0.4669	0.4608
0.7	0.6533	0.3920	0.4326	0.7226	1.0599	1.2143	0.9704	0.6343	0.6272
0.8	0.8533	0.5120	0.5740	1.0253	1.4530	1.5862	1.2342	0.8273	0.8192
0.9	1.0800	0.6480	0.7381	1.3957	1.8998	1.9979	1.5239	1.0460	1.0368
1	1.3332	0.8000	0.9263	1.8345	2.3978	2.4478	1.8558	1.2902	1.2800
2	5.3333	3.2000	4.4381	9.5912	9.7689	8.8469	6.5273	5.1403	5.1200
3	12.00	7.20	12.11	22.32	20.92	18.39	13.85	11.55	11.52
4	21.33	12.80	25.62	39.16	35.38	30.85	23.76	20.52	20.48
5	33.33	20.00	45.84	59.70	52.78	46.13	36.26	32.05	32.00
10	133.33	80.00	239.64	211.88	184.41	163.18	137.31	128.10	128.00
20	533.33	320.00	979.01	738.11	652.78	594.11	531.60	512.21	512.00
50	3333.33	2000.00	5296.83	3944.20	3626.41	3432.72	3250.70	3200.52	3200.00
100	13333.32	8000.00	18453.22	14505.63	13729.42	13289.94	12902.71	12800.80	12800.00
10000	1.3333E+08	8.000E+07	129027060	1.28E+08	1.28E+08	1.28E+08	1.28E+08	1.28E+08	1.28E+08