NUPI

[621] Working Paper

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No. 621 December – 2001

Norsk Utenrikspolitisk Institutt
Norwegian Institute of International Affairs

Utgiver: NUPI

ISSN: 0800 - 0018

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Absorptive capacity and strategic R&D investment revisited

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[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. The model in this paper is an extension of d'Aspremont and Jacquemin (1988), where they show that exogenous R&D spillovers reduce the incentive to invest in R&D when firms compete in a Cournot duopoly. Our model treats R&D spillovers as endogenous, being a function of absorptive capacity effects. Contrary to earlier studies, we show that 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 actually chose to cut down on R&D. Furthermore, absorptive capacity effects also increase the critical rate of spillovers that determines whether participating in research joint ventures leads to lower or higher R&D investment. 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.

JEL classification code: L13, O31, O32, O38
Key words: R&D investment, technology spillovers, absorptive capacity, RJV
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1. Introduction

The title of this paper is a modification of the title used by Kamien and Zang (2000) where it is emphasised that in order to be able to take advantage of the R&D and innovations produced by other firms, you will have to invest in R&D yourself (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), the fact that R&D investment both increases a firm's innovative abilities as well as its ability to learn from others, 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. As opposed to the conclusions made by Cohen and Levinthal, we claim that the stronger the absorptive capacity effect of R&D is, the smaller is the incentive to invest in R&D. It is only when the absorptive capacity is weak or the market size is small that you will actually observe higher equilibrium R&D investment than in the case with no absorptive capacity effects. This is why firms are told to *"meet me half way but don't rush"*.

A growing amount of empirical evidence in the economic literature indicates that firms which 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. In order to understand and implement ideas and concepts of others, you need to posses the competencies that enable you to decodify and utilise these ideas. Also, in order to undertake efficient surveillance of external knowledge and technology development, a rigorous understanding of the field of activities is necessary. In other words, in order to know what knowledge you are looking for, you must hold a certain amount of knowledge your self, see Levin et al. (1987) for more on this subject.

The idea that knowledge spillovers are a function of the firm's technology and knowledge intensity was already conceptualised in the early seventies (see Tilton (1971), but the idea was not discussed rigorously before Cohen and Levinthal (1989) presented a joint theoretical and empirical investigation of the subject. Their econometric analysis of US firms gives support to the concept of own R&D

dependent appropriability, a phenomenon which the authors called "the two faces of R&D".

The theoretical link between technology spillovers and the economic behaviour of firms has primarily been analysed within the school of industrial organisation.[2] Studies that ask whether such spillovers tend to affect the incentive to invest in cost-reducing or demand-increasing technology represent the main body of this literature, and game theory provides a framework in which you can investigate the strategic response of firms under alternative R&D spillover mechanisms. After the seminal paper by Brander and Spencer (1983), economists working with IO models have been able to study investment games where decisions are taken in two steps. This allows us to model behaviour where firms first decide upon the optimal investment level, and thereafter compete on the product markets. The vast majority of studies that discuss the effect of technology spillovers in strategic two stage games are based on the model developed by d'Aspremont and Jacquemin (1988) where spillovers are treated as a linear function of the opponents R&D activities.[3] Hence, they do not take into account the idea that spillovers are depending on the R&D activity of the knowledge absorbing firm. When R&D spillovers are modelled this way, d'Aspremont and Jacquemin (from here on abbreviated to DJ) implicitly assume that firms learn from external R&D without putting any efforts into the learning process. Such a feature resembles weaknesses since external R&D comes to the firms as some kind of "manna from heaven" (an expression introduced in this setting by Kamien and Zang (2000)). Symmetric models with linearly dependent spillovers provide the well known prediction that an increase in R&D spillovers discourages R&D investment in the first stage of the game. 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. However, none of these studies undertake an explicit analysis of equilibrium R&D investment where the case with exogenous R&D spillover rates are compared with the case where R&D investment improves the absorptive capacity. Cohen and Levinthal (1989) present a formal model that takes account of this effect,

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[1] See e.g. Cohen and Levinthal (1989), Kogut and Chang (1991) and Neven and Siotis (1996).
[2] At the macro level, the imperfect appropriability of knowledge forms one of the main ingredients in the study of endogenous growth processes. See for instance Romer (1986) for more on this.
[3] d'Aspremont and Jacquemin (1988), Vonortas (1994), De Bondt, Sleuwagen and Veugelers (1988)

however, the authors are not able to provide analytical results based on the full strategic effects, and hence confine the analysis to the first order effects in a 2 stage duopoly game[4]. As mentioned above, they conclude that the introduction of absorptive capacity reduces and possibly removes the disincentive effect of spillovers. Joshi and Vonortas (1996) present an elasticity characterisation of how alternative knowledge diffusion or R&D spillover mechanisms affect the decision to invest in R&D. Among the studied mechanisms, the case with own R&D effects on absorptive capacity is included. Yet, once again, we are not presented with analytical results that allow us to compare the equilibrium R&D outcomes of games with and without this kind of effect. More recently, 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 knowledge diffusion stemming from its own R&D activities. Thus, the exogenous spillover parameter introduced by DJ is endogenised. This approach may be relevant in cases where e.g. firms may decide upon degrees of patent protection or the degree of firm specific innovations. Based on a symmetric non-cooperative Cournot duopoly model, the authors show that firms may find it optimal to chose a R&D approach that limits the diffusion of knowledge to other firms. Hammerschmidt (1998) presents a model where firms undertake two kinds of investment, one that increases the ability to appropriate external knowledge and one that reduces the marginal cost of production. 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. Thus the effect of higher spillovers on total R&D investment in the firm may actually be positive. Since both of these last two studies introduce new features to the R&D investment process, their predictions can not be directly compared to the linear model developed by DJ.

In this paper, we introduce a new spillover mechanisms in the symmetric Brander-Spencer model that allows for the presence of absorptive capacity effects in R&D. The mechanism is a generalisation of the DJ model, allowing both exogenously given R&D spillover rates s as well as spillovers that depend on the own R&D investment of firms. The R&D spillover function enables us to directly compare the results

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

stemming form absorptive capacity effects with the conclusions provided by the DJ model as well as the Brander and Spencer (1983) model where spillovers are ignored. 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 actually chose to cut down on R&D.

Furthermore, when absorptive capacity effects are included, we show that the critical value on the spillover rate that determines whether joining a research joint venture (RJV) will provide higher R&D investment than the non cooperative equilibrium, is higher than in the DJ model. This implies that the likelihood of observing higher R&D investment in a RJV than in the non-cooperative game falls when we allow for absorptive capacity effects. Finally, we show that strong learning effects of own R&D is 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 effects than in a model with no spillovers at all.

In section 2 we present the spillover mechanism that allows for absorptive capacity effects and provide equilibrium R&D investment solutions to 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 model first described by Brander and Spencer (1983) and used as the model framework in DJ. Here, firms choose their investment levels x_i *(i=1,2)* in the first stage. The game structure sets no limit to what kind of investment the firm undertakes in the first stage as long as the investment is either cost-reducing or demand-increasing. Most often, however, investment is interpreted as R&D activities. At the second stage firms play a regular Cournot game in outputs q_i. In our set-up, we specifically investigate process enhancing investments, reducing costs as opposed to increasing demand. Hence, R&D investment only enters the unit cost function and not the demand function. The equilibrium output and investment level in a multi-stage game is calculated by using backwards induction, identifying the subgame prefect equilibrium R&D investment levels. Using general cost and demand functions, both firms maximise profits:

$$\pi_i = \left[p(q_i, q_j) - c_i(x_i, x_j)\right]q_i - u_i(x_i) \qquad i = 1,2 \quad i \neq j \qquad \textbf{(1)}$$

Here, the price p is a decreasing function of quantity produced, unit cost c is a decreasing function of your own as well as the opponent's R&D investments and u is the R&D investment cost function. Maximising (1) with respect to output in the second stage yields the following expression:

$$\frac{\partial \pi_i}{\partial q_i} = \frac{\partial p}{\partial q_i} q_i + p - c_i = 0 \qquad \textbf{(2)}$$

Based on the optimum output levels (q_i*, q_j*) derived in this stage from (2), firm i wants to maximise profits with respect to x_i in the first stage, which results in the following first order condition:

$$\max_{x_i} \ \pi_i = \ \Rightarrow \ \frac{\partial \pi_i}{\partial x_i} = \left(\frac{\partial p_i}{\partial q_j^*} \frac{\partial q_j^*}{\partial x_i} - \frac{\partial c_i}{\partial x_i} \right) q_i^* - \frac{\partial u_i}{\partial x_i} = 0 \qquad \textbf{(3)}$$

since $\partial \pi_i / \partial q_i = 0$ in optimum from (2). The first element within the parenthesis represents the strategic effect of R&D decisions working through the opponent's output reaction. The rest of the expression represent the direct effect of own R&D

investment. In order to study the effect of alternative spillover mechanisms, it is necessary to specify the unit cost function. To keep the analysis simple, assume that the unit cost for firm *i* is composed by a given marginal cost component b_i and the technology element g_i.

$$c_i = b_i - g_i(x_i, x_j, q_i) = b_i - x_i - q_i(x_i)x_j \qquad \textbf{(4)}$$

The function g_i represents the effective R&D investment in the firm, and is a composite of the firm's own R&D investment and the opponent's R&D investment[5]. The variable q_i describes the proportion of R&D results that spill over from firm *j* to firm *i*. As outlined in the introduction, this variable has traditionally been treated as a linear exogenous parameter $(q = g)$, where γ varies between 0 and 1 as in DJ. In that case, a value of 0 implies that no R&D results leak to the competing firm, while a value of 1 implies that all developed knowledge within the firm is shared with the competitor, i.e. full R&D spillovers.

In the model presented here, we introduce a mechanism where the R&D spillover rates are treated as a function of the firms' absorptive capacity, measured in terms of their R&D investments. First, we wish to satisfy the condition stating that $0 \leq q \leq 1$. If $q > 1$, a firm has a stronger economic gain from its competitors 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.[6] However, such a specification introduces a new dimension to the model which makes it impossible to undertake direct comparisons with the DJ model. If $q < 0$, we have a case where the competitors' R&D investment not only affect the firm's 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 loosing the race is an increasing function of the competitor's R&D investments. However, such a specification removes all

[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.
[6]Katsoulacos and Ulph (1998) develop a model where strategic R&D investment is allowed to display degrees of complementarity.

learning effects from the model, and introduces a negative externality as opposed to the positive externality we usually relate to the term 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[7]. A rather simple functional form that satisfies these two requirements is given by:

$$q_i(g_i, x_i, a) = \frac{g_i + ax_i}{1 + ax_i} \qquad 0 \leq g_i \leq 1, \quad a \geq 0, \quad x_i > 0 \qquad \textbf{(5)}$$

where g_i is the exogenous spillover rate used in the DJ model. The parameter a is a scaling parameter that regulates the size of $\partial q_i / \partial x_i$. If $a=0$, we are back to the traditional exogenous spillover mechanism used in DJ where the firm's own R&D does not affect the ability to learn from the competitor. In other words, R&D spillovers enter the firms cost function as "manna from heaven". If both a and g_i are set equal to zero, there are no spillovers at all, hence, we are back to the Brander and Spencer (1983) model.

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 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[8]. First, observe that the absorptive capacity function (5) has the following limit properties:

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

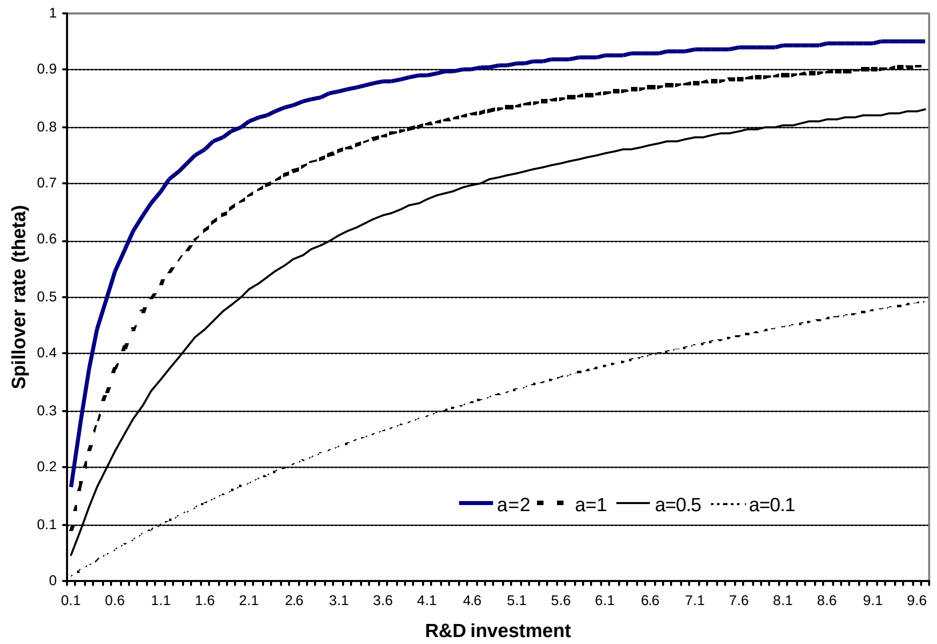
[7] A possibly more realistic learning function is based on the logistic learning curve, see Kashenas and Stoneman (1995). However, such a specification would vastly complicate the derivation of strategic responses in the game.

[8] 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 outlined restriction on spillovers. Furthermore, if the exogenous spillover parameter g_i 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[9]. Notice also that if $g_i = 1$, there is no opening for further increases in the spillover rate through own R&D investment, and the function $q(x_i)$ takes the value 1 for any size of R&D investment (x_i) . In Figure 1, we illustrate how the absorptive capacity function varies in a and x_i when there is no "manna from heaven".

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. If we allow "manna from heaven" in the absorptive capacity function, the function will simply start at g_i instead of 0 when $x_i = 0$.

Figure 1: The absorptive capacity function with no manna from heaven



9 This aspect is also discussed by Kamien and Zang (2000).

Using (5), the effective R&D investment function outlined in (4) now takes the following form:

$$g_i(g_i, x_i, x_j, a) = x_i + q_i x_j = x_i + \left(\frac{g_i + a x_i}{1 + a x_i}\right) x_j \qquad \textbf{(6)}$$

where we have abbreviated $q_i(l_i, x_i, a) \equiv q_i$ for expositional simplicity. Throughout the analysis, we assume that the products are homogenous and that the firms face the following linear demand function

$$p = a - q_i - q_j, \qquad \textbf{(7)}$$

implying that firms confront the same market price. Finally, to ensure equilibrium, it is assumed that the investment cost function in (1) is quadratic, $u_i(x_i) = \frac{1}{2} x_i^2$, which guarantees decreasing returns to R&D. Substitution for the general expression in (2) using the cost function in (4), gives the following Cournot-Nash equilibrium output levels:

$$q_i^* = \frac{1}{3}\left(m_i + (2 - q_j)x_i + (2q_i - 1)x_j\right) \qquad \textbf{(8)}$$

where $m_i = a - 2b_i + b_j > 0$ in order to ensure positive outputs. In line with standard Cournot duopoly analysis, if firm *i* has a cost advantage ($b_i < b_j$), the firm will capture a higher market share than the competitor, ceteris paribus. In the following discussion of the model, the variable m_i plays a pivotal role. In the previous literature, the variable has usually been named the *"demand cost margin"* as it says something about how large variable costs are relative to the market size. A larger m_i 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.

The more R&D that spills over from firm *j* to firm *i* described by q_i, the higher will firm *i's* output and profit be relative to the competitors output and profit[10]. Also, the larger the leakage of firm *i's* own R&D results, described by q_j, the lower will its output and profit be. We now use (8) and the quadratic investment cost function to

[10] Remember that profit in a Cournot duopoly of this kind is given by $p_i = q_i^2 - u_i(x_i)$

derive the first order condition for optimal R&D investment in the first stage of the game from (3), which yields:

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

If we further assume that firms are symmetric, we can drop all firm specific subscripts and provide the following first order condition in the symmetric game:

$$\frac{\partial p}{\partial x} = 4(1+q)\frac{\partial q}{\partial x}x^2 + \left(4m\frac{\partial q}{\partial x} + 2(2-q)(1+q) - 9\right)x + 2m(2-q) = 0 \qquad \textbf{(10)}$$

Furthermore, inserting our endogenous R&D spillover function (5) into (10) gives the following first order condition for a firm in the symmetric game with absorptive capacity effects:

$$\frac{\partial p}{\partial x} = \frac{2}{9}\left(m(1+ax) + x(1+g+2ax)\right)\left(2 - \frac{g+ax}{1+ax} + 2x\frac{a(1-g)}{(1+ax)^2}\right) - x(1+ax) = 0 \qquad \textbf{(11)}$$

Notice that in the case with no absorptive capacity effects (*a=0)* as in the DJ model, we have that $q = g$ and $\partial q/\partial x = 0$, and as described by DJ, (11) has an explicit and unique solution for symmetric non-cooperative equilibrium R&D investment (x*) in both firms:

$$x^* = \frac{2m(2-g)}{9 - 2(2-g)(1+g)} \qquad \textbf{(12)}$$

Notice that a larger market size (m) gives a stronger incentive to invest in R&D, independently of the size of the spillover parameter.[11] This implies that the gains from investing in R&D is growing in m since the cost reducing effect of R&D affects a larger volume of sales in the second stage of the game, driving profits to a higher level. To map the effect of R&D spillovers on equilibrium R&D investment in the DJ model, we take the derivative of (12) with respect to γ, which yields:

$$\frac{\partial x^*}{\partial g} = -\frac{2m(1+8g-2g^2)}{\left(9-2(2-g)(1+g)\right)^2} \leq 0 \quad \text{since } 0 \leq g \leq 1 \qquad \textbf{(13)}$$

[11] If there are no spillovers at all (γ=0), equilibrium R&D investment becomes *x*=4m/5*.

Thus, a higher spillover rate in a symmetric game without absorptive capacity effects leads to lower equilibrium R&D investment. This is due to well known dis-incentive effect of spillovers in symmetric games highlighted by DJ. Firms are less willing to invest in R&D since the positive effect on profits through a cost reduction is outweighed by the negative strategic effect driven by the cost reducing effect of spillovers on the competitor's costs.

Now, let us return to our case with absorptive capacity effects. Rearranging (11) gives the following 4. order polynomial in R&D investment, under the assumption that there is no "manna from heaven"($g=0$):

$$\frac{\partial p}{\partial x} = m\left(4 + 14ax^{*} + 12a^{2}x^{*2} + 2a^{3}x^{*3}\right) - 5x^{*} - 9ax^{*2} - 5a^{2}x^{*3} - 5a^{3}x^{*4} = 0 \quad \textbf{(14)}$$

The case with "manna from heaven" is discussed later in this section. Notice that the equilibrium R&D investment based on the absorptive capacity function (5) becomes solely an implicit function of the market size (m) and the learning parameter (a). Thus we can study the equilibrium R&D level as a function of these variables only. There exist no explicit solution for the equilibrium R&D investment in this game as outlined by (14), yet it is possible to analyse the behaviour for all combinations of a and m using numerical simulations[12]. The second order condition and Tatônnement requirement for local stability are satisfied for all parameter combination. A discussion of these conditions is presented in Appendix 1.

In figure 2, we simulate the equilibrium R&D investment in 4 different games, all without "manna from heaven", i.e. $\gamma=0$. The first game is illustrated by the thick full line, which describes R&D investment in the game allowing for absorptive capacity effects with the learning parameter $a=1$. The second game is illustrated by the thin and linear line that describes R&D investment in a game where we have no absorptive capacity effects ($a=0$). Thus, this is equivalent to the Brander and Spencer game with no spillovers at all, where firms over-invest in R&D. Here, the equilibrium R&D investment is simply given by $x^{*} = 4m/5$. In the third game (the thin dotted line), the DJ model is simulated with a spillover rate γ=0.5. The reason why we present this

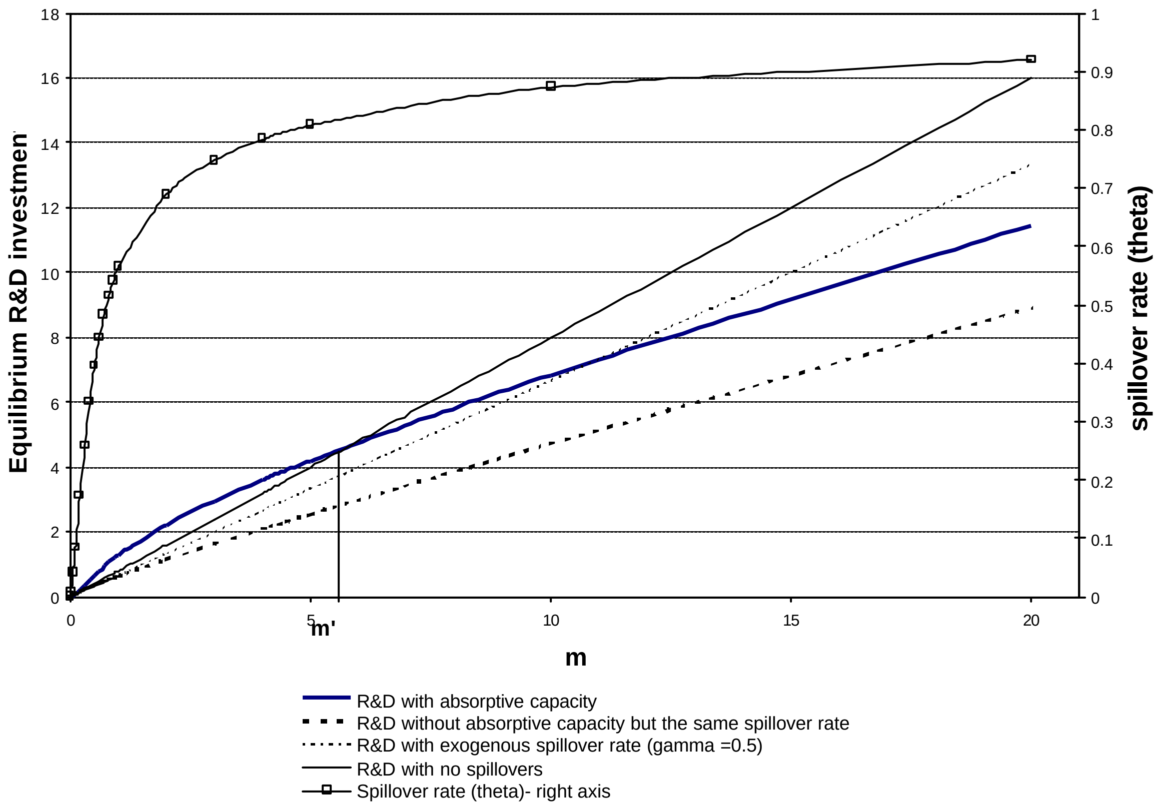
[12] The expression in (14) has four solution: Two of them have complex roots, one is always negative and one is always positive. Hence, we focus on the real and non-negative solution since negative R&D investments give no clear meaning in the game.

game is that the DJ model predicts that firms will neither under-invest nor over-invest in R&D at this spillover rate. In the fourth game (the thick dotted line), we translate the spillovers generated by the absorptive capacity effects ($a=1$) in the first game into exogenous spillover rates. In mathematical terms we set:

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

In other words, we study how equilibrium R&D investment in the DJ model compares to our model, using the same spillover rate. This spillover rate θ* varies with the size of m and is represented by the marked line that converges to 1 as m grows (see the right vertical axis). Thus, the generated spillover rate applies to both the thick full line and the thick dotted line.

Figure 2: Equilibrium R&D investment in 3 different games



The simulations in Figure 2 suggest that R&D investment in the absorptive capacity game (the thick full line) will always be higher than in a DJ game where the exogenous spillover rate is set equal to the spillovers generated in the absorptive capacity game, (i.e. $\gamma=\theta^*$) (the thick dotted line). It is actually possible to prove that this is true for any absorptive capacity mechanism where own R&D improves the ability to learn form others. The proof is based on closer investigation of the first order condition (10) where the absorptive capacity mechanism is expressed in general terms.

Proposition 1: *If the exogenous spillover rate (g) in the symmetric DJ game,* $0 \le g \le 1$, *is the same as the spillover rate (q*) generated by the symmetric game with absorptive capacity effects but no manna from heaven, equilibrium R&D investment in the DJ game will always be lower than in the absorptive capacity 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

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

in the first order condition in (10). Then, we know from (10) 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 DJ case, we must have that $\bar{x} < \hat{x}$. For this to be the case, the following deviation must be satisfied: $C\hat{x} - C\bar{x} = -A\bar{x}^2 - B\bar{x} > 0$, but this is not possible for non-negative R&D investment levels. QED.

Proposition 1 tells us that spillovers work differently in the absorptive capacity model as compared to the DJ model where spillovers are exogenous. 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 name 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 Figure 2, we see that the positive learning effect is growing in *m* but that the marginal contribution of *m* is decreasing. It is important to notice that when we now go on with comparing the equilibrium R&D investment level in the absorptive capacity model with the DJ model, it is the interplay between these two effects that drives the conclusions.

Table 1: Equilibrium R&D investment under alternative combinations of *a* and *m*

m	***a=0***	***a=0***	***a=0.1***	***a=0.5***	***a=1***	***a=2***	***a=10***	***a=1000***	***a=1bn***
	g=0	*g=0.5*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*
	No spillovers	Manna from heaven							
0.0001	0.00008	0.000067	0.00008	0.00008	0.00008	0.00008	8.01E-05	9.17E-05	**4E-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**

For values of *m* larger than *m'* in Figure 2, R&D investment is lower in the game with absorptive capacity effects than the game without spillovers. At even higher values of *m*, R&D investment in the absorptive capacity game actually also undercuts the investment level generated by the DJ model with a spillover rate γ=0.5. In Table 1, we calculate the equilibrium R&D investment as a function of *m* and *a*, spanning out the range of *a* from 0.1 to 1 billion in order to ensure the reader that the patterns depicted in Figure 2 are representative for all possible values of the learning parameter *a*. The shaded area in Table 1 represents all those combinations of *m* and *a* where R&D

investment is lower in the absorptive capacity game than in the game with no spillovers. The lightly shaded areas represents the cases where R&D investment is also lower than in the DJ game with an exogenous spillover rate set to $g=0.5$. The reported figures clearly show that as the learning parameter *(a)* increases, the critical size of $m=m'$ 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 (m>m'), 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 DJ game with exogenous spillovers.*

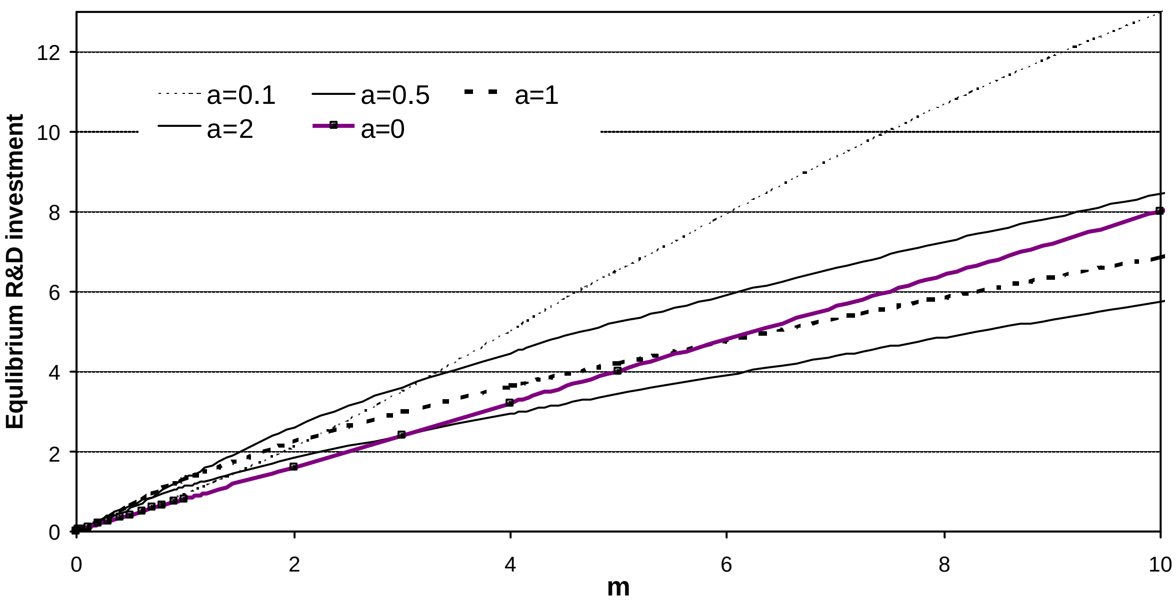
Result 2: *If the learning parameter a is increased, the critical size of the market (m') falls. This implies that the range of the market size for which R&D investment is lower in the absorptive capacity game than the game without spillovers, is widened.*

On the other hand, it is important to notice that with a sufficiently small *m* ($m<m'$), the absorptive capacity game actually generates higher R&D investment than a game with no spillovers. Thus, in a case where the market size is small or marginal costs are high, our model predicts that spillovers will give an extra incentive to invest in R&D. This result also contrasts the earlier theoretical literature on spillovers.

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 (13), we know that for any exogenously given spillover rate *g* in the DJ model, there is a positive and linear relationship between the size of the market (*m*) and the strength of the *negative traditional effect of spillovers* on R&D investment. This effect is best illustrated by the increasing gap between equilibrium R&D investment in the game with no spillovers and the DJ game with $g=0.5$ as *m* grows in Figure 2. Although the *positive learning effect* also grows with the size of *m*, the growth rate is decreasing. This is due to the way we model the absorptive capacity mechanism in (5). A larger market drives up equilibrium R&D investment, but as equilibrium R&D investment increases due to a higher *m*, the marginal capacity to absorb external R&D falls. Therefor, the increase in the positive learning effect of own R&D is falling with the size of m. Consequently, at a sufficiently large market size ($m>m'$), 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. Alternatively, since the endogenously determined spillover rate q (the marked line in Figure 2) grows towards 1 as m increases, the equilibrium R&D investment in the absorptive capacity game will eventually be lower than the R&D investment in the DJ game where $g<1$.

The intuition behind result 2 can also be related to the spillover mechanism in (5). We know from proposition 1 that there exists a positive learning effect on R&D investment in the game with absorptive capacity effects. When the learning parameter a is increased, the positive learning effect is also strengthened. However, a higher value of a 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 faster. Consequently, we will observe that the critical level m' is reduced as the learning parameter a is increased.

Figure 3: Equilibrium R&D investment for varying learning parameter values



The impact of changing the learning parameter a on equilibrium R&D investment is illustrated in Figure 3, where we describe the same exercise as in Table 1, but for expositional purposes only report for a selection of values of a. The thick marked line in Figure 3 is once again the Brander and Spencer game where $a=0$ (no spillovers). The case where a is large is illustrated by the thick unmarked line $(a=2)$. When we compare this case with the cases based on lower parameter values, we once again observe the interplay between the two effects. The positive learning effect dominates when (m) is small, implying that a large a generates the highest equilibrium R&D investment level. But in larger markets, the negative traditional spillover effect is magnified by a, driving down R&D investment. The thin dotted line represents the case with a very small learning parameter $a=0.1$. Here, for small values on m, the equilibrium R&D level will be only marginally higher than in the case without spillovers $(a=0)$ but significantly smaller than in the case with large learning effects, basically due to the smaller positive learning effect . However, if we increase m in this case, the negative impact on equilibrium R&D investment will be moderated since the spillover rate q grows slower in own R&D investment when a is small. Consequently, for large values on m, the equilibrium R&D investment level is higher the smaller the learning parameter is[13].

Allowing both endogenous and exogenous spillovers

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. One may 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. For instance, if the R&D results are available to the public through the school or university system, the cost of acquiring this knowledge is low.

[13] In Figure 3, it looks like the line representing a=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.

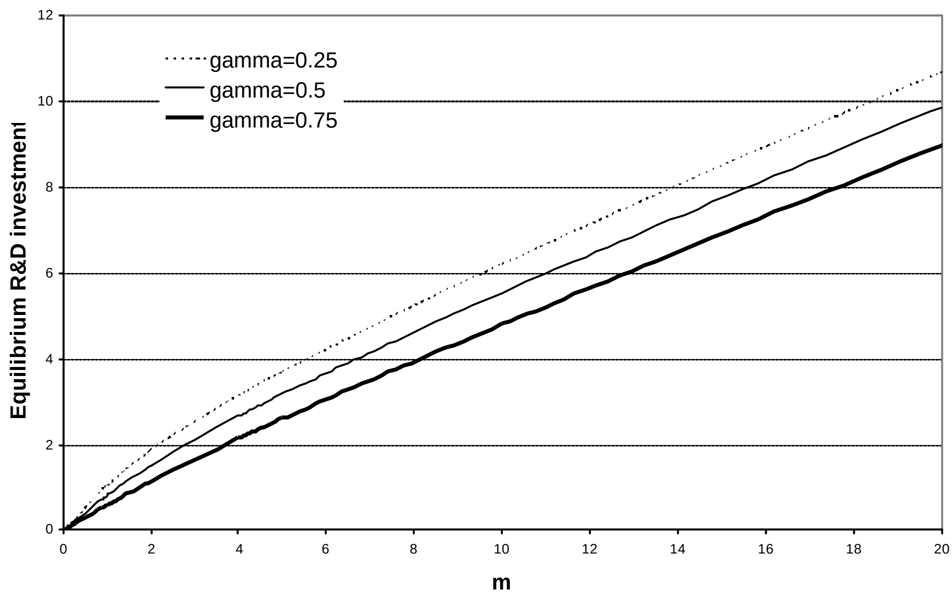
When we also allow exogenous R&D spillovers in the model, the first order condition for optimal R&D investment becomes slightly more complex:

$$m\left(4+14x^{*}+12x^{*2}+2x^{*3}-8\gamma x^{*}-6\gamma x^{*2}-2\gamma\right)$$
$$-5x^{*}-9x^{*2}-5x^{*3}-5x^{*4}+2\gamma x^{*}-10\gamma x^{*3}-6\gamma^{2}x^{*2}-2\theta^{2}x^{*}=0 \qquad \textbf{(15)}$$

In (15) we have set *a=1*, and the effect of changing γ is illustrated in Figure 4. Clearly, a higher γ contributes to lower R&D investment, just as described in DJ. This illustrates that the introduction of exogenous R&D spillovers only works through the traditional negative spillover effect on R&D investment as in DJ, although the γ parameter actually enters the absorptive capacity function in (5). Hence, when the games include "manna from heaven", the critical value of *m=m'* is 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 remark:

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 m' falls with a higher* γ.

Figure 4: Equilibrium R&D investment in the game with absorptive capacity (a=1) and varying degrees of "manna from heaven"



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 to the possibility that the opponent may invest more and capture some of the firm's profit in the output game. As shown by e.g. d'Aspremont and Jacquemin (1988), 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 on the output market in the second stage of the game, firms internalise the external effect of R&D spillovers in the first stage of the game. 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:

$$\max_{x_i, x_j} (\pi_i + \pi_j) = \max_{x_i, x_j} \Pi = q_i^2 + q_j^2 - u(x_i) - u(x_j) \qquad \textbf{(16)}$$

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

$$\frac{\partial c_i}{\partial x_i} q_i + \frac{\partial u_i}{\partial x_i} = 0 \qquad \textbf{(17)}$$

Since the second order condition for the optimisation problems in (17) has the following property: $\frac{\partial^2 c_i}{\partial x_i^2} + \frac{\partial^2 u_i}{\partial x_i^2} \geq 0$, a firm will be under-investing in the non-cooperative equilibrium if the expression on the left hand side of (17) is negative. This is so, since an increase in investment will cut unit costs more than it contributes to increase investment costs. Over-investment, on the other hand, is associated with a positive value.

Using the first order condition in (3) and the assumption of symmetry, the condition (17) specified in the non-cooperative case with no absorptive capacity ($a=0$) gives the following expression:

$$\frac{\partial c_i}{\partial x_i} q_i + \frac{\partial u_i}{\partial x_i} = \frac{\partial \pi_i}{\partial q_j} \frac{\partial q_j}{\partial x_i} q_i = \frac{1}{3}\theta(1-2\gamma) \qquad \textbf{(18)}$$

where θ is non-negative. This provides us with the well known result from the DJ model with exogenous spillovers, stating that firms will under-invest in R&D as long as the spillover rate is higher than $\gamma^{**}=0.5$. 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 ($\gamma=0$).

$$\frac{\partial c_i}{\partial x_i} q_i + \frac{\partial u_i}{\partial x_i} = \frac{\partial \pi_i}{\partial q_j} \frac{\partial q_j}{\partial x_i} q_i = \frac{1}{3}\theta\left(\frac{1+\alpha x(1-\alpha x)}{(1+\alpha x)^2}\right) \qquad \textbf{(19)}$$

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

$$\alpha x = \frac{1+\sqrt{5}}{2} \qquad \Rightarrow \qquad \theta^{**}(\alpha, x, \gamma=0) = \frac{1+\sqrt{5}}{3+\sqrt{5}} \approx 0{,}618 \qquad \textbf{(20)}$$

This gives a clear interpretation of the consequence of implementing absorptive capacity effects in a Cournot duopoly with R&D spillovers.

Proposition 2: *The critical rate of spillovers (θ^{**}) where 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 as compared to the case with exogenous R&D spillovers.*

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

The logic behind Proposition 2 relates directly to Proposition 1 and the findings in Figure 2. Since firms in the game with absorptive capacity effects always invest more than in the game without such effects but the same R&D spillover rate ($\gamma=\theta^*$), we know that the investment level with absorptive capacity effects will be higher when $\theta^*=\gamma=0.5$. Thus, the introduction of absorptive capacity effects increases the range of spillover rates where firms over-invest in R&D. With the functional forms studied here, the question of whether firms over-invest or alternatively under-invest can be studied by looking at the difference between the solution to the objective function in

(3) and the solution to the cost minimization problem for a given output level. Notice that a consequence of Proposition 2 is that firms will over-invest in R&D for a wider range of R&D spillovers in the game with absorptive capacity effects as compared to the game with exogenous R&D spillovers.

4. The welfare effects of absorptive capacity

In order 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 inverse demand function in (7), consumer surplus is given by:

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

Thus, welfare is simply given by:

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

In the DJ model where the R&D spillover rate is given exogenously, we find that the spillover rate that provides the highest welfare is given by[14]:

$$\begin{aligned} \frac{\partial W}{\partial g} = 8q^*\left(\frac{\partial q^*}{\partial g} + \frac{\partial q^*}{\partial x^*}\frac{\partial x^*}{\partial g}\right) - 2x^*\frac{\partial x^*}{\partial g} = 0 \\ \Rightarrow \quad 20 + 2g^3 - 12g^2 - 21g = 0 \end{aligned} \tag{23}$$

Using Cardanos formula for a cubic equation leaves us with $g^w=0.70304$ as the only solution to the optimisation problem in (23) that satisfies the condition *0£g£1*. From (18) we know that firms will under-invest in R&D at this spillover rate. Hence, given that firms compete in a Cournot duopoly, the socially optimal R&D investment level is below the firms' cost minimising R&D investment level e.g. obtained through a RJV.

[14] The second order condition requires that $148\gamma+4\gamma^4-72\gamma^2-32\gamma^3-5>0$ which is satisfied for all values of $\gamma>0.034367$.

In Table 2 we report the results from numeric simulations of welfare outcomes under alternative market sizes (m) and absorptive capacity effects (a). The shaded observations represent the value on the learning parameter $a=a^w(m)$ that provide the highest welfare outcome for alternative market sizes. It is important to notice that in contrast to the DJ model, there does not exist a 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. Highest welfare in a small market is reached when the absorptive capacity effect of R&D (a) 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 3. We know from section 2, that when the market size (m) is small, the positive learning effect of R&D has a relatively strong impact on R&D investment as compared to 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 (a) generates high equilibrium R&D investment. In Figure 3, 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 numeric simulations, the welfare level will never be lower in the model with absorptive capacity effects ($a>0$) than in the model without spillovers ($a=0$). This result mimics the result based on the DJ model. The logic relates directly to how R&D spillovers affect equilibrium output. In the DJ model, the highest output is reached when the R&D spillover rate $\gamma=0.5$, and the equilibrium output declines symmetrically around this point[15]. Similarly, since the absorptive capacity mechanism generates spillovers in the model, it is only when $a=$¥ that output gets as low as when $a=0$.

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

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

m	*a=0*	*a=0*	*a=0*	*a=0.1*	*a=0.5*	*a=1*	*a=2*	*a=10*	*a=1000*	*a=1bn*
	g^w *=0.70304*	*g=0.5*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*	*g=0*
	Manna from heaven		No spillovers							
0.0001	1.3940E-08	1.3378E-08	8.00E-09	8E-09	8E-09	8E-09	8E-09	8.01E-09	9.26E-09	1.28E-08
0.001	1.3940E-06	1.3244E-06	8.00E-07	8E-07	8.01E-07	8.01E-07	8.02E-07	8.1E-07	1.45E-06	1.28E-06
0.01	1.3940E-04	1.3244E-04	8.00E-05	8.01E-05	8.05E-05	8.1E-05	8.21E-05	9.26E-05	0.000184	0.000128
0.05	0.0035	0.0033	0.0020	0.0020	0.0021	0.0021	0.0023	0.0046	0.0036	0.0032
0.1	0.0139	0.0133	0.0080	0.0081	0.0086	0.0093	0.0111	0.0240	0.0137	0.0128
0.2	0.0558	0.0533	0.0320	0.0329	0.0371	0.0444	0.0641	0.0977	0.0532	0.0512
0.3	0.1255	0.1200	0.0720	0.0749	0.0909	0.1211	0.1821	0.2092	0.1182	0.1152
0.4	0.2230	0.2133	0.1280	0.1351	0.1775	0.2562	0.3632	0.3538	0.2088	0.2048
0.5	0.3485	0.3333	0.2000	0.2142	0.3057	0.4599	0.5995	0.5283	0.3250	0.3200
0.6	0.5018	0.4800	0.2880	0.3131	0.4847	0.7277	0.8844	0.7346	0.4669	0.4608
0.7	0.6830	0.6533	0.3920	0.4326	0.7226	1.0599	1.2143	0.9704	0.6343	0.6272
0.8	0.8921	0.8533	0.5120	0.5740	1.0253	1.4530	1.5862	1.2342	0.8273	0.8192
0.9	1.1291	1.0800	0.6480	0.7381	1.3957	1.8998	1.9979	1.5239	1.0460	1.0368
1	1.3940	1.3332	0.8000	0.9263	1.8345	2.3978	2.4478	1.8558	1.2902	1.2800
2	5.5758	5.3333	3.2000	4.4381	9.5912	9.7689	8.8469	6.5273	5.1403	5.1200
3	12.55	12.00	7.20	12.11	22.32	20.92	18.39	13.85	11.55	11.52
4	22.30	21.33	12.80	25.62	39.16	35.38	30.85	23.76	20.52	20.48
5	34.85	33.33	20.00	45.84	59.70	52.78	46.13	36.26	32.05	32.00
10	139.40	133.33	80.00	239.64	211.88	184.41	163.18	137.31	128.10	128.00
20	557.58	533.33	320.00	979.01	738.11	652.78	594.11	531.60	512.21	512.00
50	3484.90	3333.33	2000.00	5296.83	3944.20	3626.41	3432.72	3250.70	3200.52	3200.00
100	13939.61	13333.32	8000.00	18453.22	14505.63	13729.42	13289.94	12902.71	12800.80	12800.00
10000	1.3940E+08	1.3333E+08	8.000E+07	1.29E+08	1.28E+08	1.28E+08	1.28E+08	1.28E+08	1.28E+08	1.28E+08

Result 5: *For any market size (m), there always exists a learning parameter value* $a^w(m)$*, such that welfare in the model with absorptive capacity effects is higher than the welfare obtained in the DJ model with the optimal spillover rate* g^w *.*

Result 5 is based on the simulations in Table 2 and highlights the importance of the positive learning effect of absorptive capacity. By continuity, there will always exist a learning parameter value that generates the spillover rate g^w in equilibrium, but since the positive learning effect of own R&D is always present for $a>0$, this specific value will provide higher R&D investment than in the DJ game based on g^w.

5. Conclusions and prospects for further research.

The main message in this paper states 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 has been 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 as compared to the case with exogenous R&D spillovers, is predominantly a question of market size. If the market size is small, the absorptive capacity effect will drive up R&D investment, while the opposite is true when the market size is large.

We explain this result trough 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 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 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 as compared to a game without such effects.

The model presented in this study, has the advantage of being directly comparable with the model developed by d'Aspremont and Jacquemin (1988) (DJ). 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 outlined by Cohen and Levinthal (1989) where absorptive capacity effects unambiguously increases the incentive to invest in R&D, is questioned in this study.

The conclusions from this paper also add new insight into the theory of research joint ventures (RJVs). We show that for any given spillover rate, firms in the absorptive capacity game will find it optimal to invest more in R&D, implying that the R&D spillover rate that provides cost minimising R&D investment levels is higher in the absorptive capacity model. Broadly speaking, this means that *ceteris paribus*, more firms will over-invest in R&D as compared to what is predicted in the models with exogenous R&D spillover rates. This implies that the introduction of a RJV will force up R&D investments in fewer cases.

Finally, the model shows that strong learning effects of own R&D is 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 effects than in a model with no spillovers at all.

The conclusions derived in this study 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 studies should devote resources to the impact of absorptive capacity effects in asymmetric games, where the outlined effects may be modified. However, studying asymmetric games of this kind is a complex analytical task, yet numerical simulations may also provide valuable insights to the R&D investment response of firms.

Appendix 1

The second order condition $\partial^2 \pi_i / \partial x_i^2 < 0$ using (14), gives the following condition for a global maximum:

$$m(14a + 24a^2 x + 6a^3 x^2) - 5 - 18ax - 15a^2 x^2 - 20a^3 x^3 < 0 \qquad \textbf{(1A)}$$

Notice that as opposed to the case with no absorptive capacity effects $(a=0)$ where the demand cost margin (m) does not affect the curvature of the profit function (the first expression on the left hand side falls out), in the case with such effects, this variable does play a role. Numerical simulations based on equation (14) shows that all combinations of m and a, satisfy the second order condition locally around the R&D equilibrium.

An important requirement in the analysis of Cournot games, which is much to often ignored, is the stability of the equilibrium. A small deviation from the equilibrium R&D strategies may either bring the game back to the equilibrium outcome or generate unstable patterns. The commonly used Tatônnement requirement for local stability of an equilibrium is given by (see Vives (1999)):

$$\left|\frac{\partial^2 p_i}{\partial x_i^2}\frac{\partial^2 p_j}{\partial x_j^2}\right| > \left|\frac{\partial^2 p_i}{\partial x_i \partial x_j}\frac{\partial^2 p_j}{\partial x_j \partial x_i}\right| \qquad \textbf{(2A)}$$

The combinations of a and m that fulfil this stability condition are reported in Table A1. A direct comparison of the figures in Table 1 and Table A1, shows that for no values of a>0 is the critical value on $m = m''$ for where stability is satisfied, larger than m'. Thus, there is always a range for which equilibrium R&D investment is larger in the case with absorbtive capacity effects than the case without R&D spillovers, and both the second order and local stability conditions are satisfied.

Table A1: Stability values - Local stability of equilibrium is satisfied for all values >0

m (g=0)	*a=0*	*a=0.1*	*a=0.5*	*a=1*	*a=2*	*a=10*	*a=1000*	*a=1bn*
0.0001	-0.18519	-0.18518	-0.18517	-0.18515	-0.18511	-0.18483	-0.14812	2.43E+19
0.001	-0.18519	-0.18515	-0.18501	-0.18483	-0.18447	-0.18161	0.084127	2.42E+23
0.01	-0.18519	-0.18482	-0.18336	-0.18153	-0.17784	-0.14742	7772.876	2.38E+27
0.05	-0.18519	-0.18318	-0.17514	-0.16504	-0.14467	-0.04177	2063838	1.36E+30
0.1	-0.18519	-0.18079	-0.16321	-0.14145	-0.09981	0.537954	24621769	1.96E+31
0.2	-0.18519	-0.17506	-0.13562	-0.09109	-0.02973	9.823455	2.86E+08	2.56E+32
0.3	-0.18519	-0.16842	-0.10543	-0.04393	0.036067	33.65045	1.14E+09	1.06E+33
0.4	-0.18519	-0.16112	-0.07441	-0.00137	0.132156	71.66059	2.91E+09	2.77E+33
0.5	-0.18519	-0.15336	-0.04362	0.038945	0.256739	121.7234	5.82E+09	5.62E+33
0.6	-0.18519	-0.1452	-0.01381	0.07657	0.398599	182.7786	9.98E+09	9.72E+33
0.7	-0.18519	-0.13683	0.014501	0.112685	0.548857	252.2102	1.54E+10	1.51E+34
0.8	-0.18519	-0.12823	0.040926	0.146972	0.701497	327.8288	2.21E+10	2.17E+34
0.9	-0.18519	-0.11952	0.065271	0.178829	0.852697	407.5487	2.98E+10	2.94E+34
1	-0.18519	-0.11069	0.087513	0.20844	1.000166	493.6661	3.85E+10	3.82E+34
2	-0.18519	-0.0227	0.226881	0.411332	2.145467	1305.887	1.47E+11	1.47E+35
3	-0.18519	0.055237	0.294522	0.519855	2.784601	1859.787	2.35E+11	2.36E+35
4	-0.18519	0.117552	0.335886	0.584764	3.125051	2148.759	2.82E+11	2.83E+35
5	-0.18519	0.164964	0.364503	0.626756	3.294537	2257.399	2.99E+11	3.01E+35
10	-0.18519	0.284311	0.436288	0.70486	3.231196	1879.252	2.39E+11	2.39E+35
20	-0.18519	0.36515	0.485828	0.71279	2.532095	1009.119	1.17E+11	1.17E+35
50	-0.18519	0.438628	0.524634	0.666285	1.540967	284.6523	2.92E+10	2.92E+34
100	-0.18519	0.478092	0.539835	0.625575	1.072374	92.53513	8.52E+09	8.53E+33
10000	-0.18519	0.554064	0.555407	0.556479	0.560743	0.715659	999500.8	9.98E+29

Stability values are based on local Tatônnement stability calculated in the following way:

$$\left|\frac{\partial^2 p_i}{\partial x_i^2}\frac{\partial^2 p_j}{\partial x_j^2}\right| - \left|\frac{\partial^2 p_i}{\partial x_i \partial x_j}\frac{\partial^2 p_j}{\partial x_j \partial x_i}\right|$$

Acknowledgements

This research has been financed by the Norwegian Research Council under the program Næring, finans og marked; grant number 124567/510. I am grateful to Jan Fagerberg, Tore Nilssen, Arne Melchior and the participants at the 2001 EARIE conference. They all provided me with useful comments and guidance. The usual disclaimer applies.

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