Innovative Output, Infra-Industry Spillovers, and R&D Cooperation: Theory and Evidence[1]

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Abstract

We analyse both the theoretical and the empirical side of the issue of R&D spillovers. Each firm's R&D costs are increasing in the amount of information transmitted to other firms, and we account for the possibility that firms control spillovers. We consider both Cournot-Nash and Cournot-Stackelberg behaviour. The empirical analysis suggests that (i) firms' control on spillovers is relatively low; (ii) the cost-saving effect associated to joint ventures or R&D cartels is confirmed for industries where firms rely mainly upon own R&D as a source of innovation; (iii) R&D cooperation may increase information sharing, thereby enhancing spillovers.

JEL Classification: L13, O31

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1 Introduction

Appropriability has long been identified as a major problem facing the innovating firm. Since it can hardly appropriate the benefits connected to its innovations, it is very likely that such firm will not perform the desired R&D projects, its possibility to fully exploit their results being threatened by rival firms. A solution to this dilemma is cooperative R&D, either conducted by firms who share the costs and benefits of particular R&D projects, or consisting in informal trading of proprietary know-how between rival firms (von Hippel, 1987; 1988).

A large empirical debate has unfolded over the last twenty years, concerning the magnitude of R&D spillovers (for an overview, see Geroski, 1995a,b; and Griliches, 1995; *inter alia*). The overall appraisal maintains that technological externalities are widespread both inter- and intra-industry, although their magnitude varies considerably across industries.[1]

This discussion has triggered a corresponding theoretical approach to the analysis of R&D spillovers (see d'Aspremont and Jacquemin, 1988; Henriques, 1990; Katz and Ordover, 1990; de Bondt *et al.*, 1992; Kamien *et al.*, 1992; Suzumura, 1992). This literature conducts comparative statics upon equilibrium outputs and investments across alternative organizational designs such as R&D cartels and research joint ventures (RJVs) vs noncooperative independent ventures. This analysis is carried out so as to point out whether arrangements like RJVs and R&D cartels may help firms overcome the wasteful effort duplication effect associated with strictly noncooperative behaviour in the R&D phase.

However, in the aforementioned literature, technological externalities are considered as exogenous to firms. This assumption is arguable, in that RJVs and R&D cartels may indeed justify the idea that firms share their knowledge to a larger extent than they would in case of independent ventures. That is, any form of cooperation in R&D may allow firms not only to reduce individual as well as industry expenditures, but also to internalise externalities as much as possible through the endogenous manoeuvring of spillovers.

To our knowledge, the existing contributions exploring this issue are those of Katz (1986), Katsoulacos and Ulph (1998) and Poyago-Theotoky (1999). In particular, Katsoulacos and Ulph (1998) evaluate the behaviour of a research joint venture (RJV) against independent ventures, to find that the spillovers associated with an RJV are at least as high as those associated with the alternative arrangement. On the contrary, a recent empirical contribution by Cassiman and Veugelers (1999) finds that the probability of cooperating in R&D is directly related to appropriability (i.e., the probability increses with incoming spillovers and decreases with outgoing spillovers).

In this paper, we analyse both the theoretical and the empirical side of the is-

[1] In particular, for inter-industry spillovers in R&D activities, see Bernstein and Nadiri (1988).

sue of information sharing, or technological externalities. The theoretical analysis is carried out along the approach introduced by Amir (1998), where each firm's R&D costs are increasing in the amount of information transmitted to other firms. We extend his analysis to account for the possibility that firms control spillovers. As a benchmark, we reassess the largely discussed case of a symmetric Cournot duopoly. Then, we investigate an asymmetric Cournot-Stackelberg duopoly where one firm is the leader at the market stage. The main results can be summarised as follows.

First, consider Cournot-Nash behaviour at the marketing stage. A joint venture, being an organisational design meant to favour information sharing, involves larger spillovers than independent ventures. Then, there emerges that joint profit maximisation at the R&D stage (R&D cartel) has a cost-saving effect as compared to noncooperative behaviour if and only if spillovers are low enough. This entails that, if spillovers are endogenously controlled, independent ventures provide the right incentives towards cost saving.

Second, consider Cournot-Stackelberg behaviour at the market stage. Here, we only examine strictly noncooperative behaviour w.r.t. spillovers and R&D efforts. We find that (i) the leader's R&D investment is larger than the follower's if the spillover from the former towards the latter is sufficiently low; (ii) if firms completely control their respective spillovers, the leader invests less than under the Nash equilibrium solution, while the opposite holds for the market follower.

We test some of the implications of the theoretical analysis using a micro-aggregated version of the first Community Innovation Survey (CIS) database provided by Eurostat, in relation to four industries (textiles, clothing, chemicals and mechanical engineering) in manufacturing for five EU countries: Belgium, Denmark, Germany, Italy, and Norway. Concentration is measured by the Linda index.

Our findings can be summarised as follows. First, the empirical investigation suggests that the extent to which firms endogenously control spillovers is relatively low. Second, for textiles and clothing, the empirical test supports the claim that R&D cooperation entails a higher level of R&D effort. The opposite emerges concerning R&D intensity in chemicals and mechanical engineering. The results obtained from the *scale intensive* (Textiles) and the *supplier dominated* (Clothing) industries suggest that when own R&D is not as relevant as other sources of technological improvement, cooperating in R&D may enhance the commitment, and improve the ability, to carry out own R&D. Third, in three industries the tests confirm that R&D cooperation may increase information exchange between firms, thereby enhancing spillovers.

The remainder of the paper is structured as follows. The theoretical analysis is carried out in section 2. The data set is described in section 3. Section 4 contains the exposition of empirical results. Finally, concluding remarks are in section 5.

2 The theoretical setup

We borrow the theoretical framework from Amir (1998, see also Hinloopen, 1997). We consider a duopoly where quantity-setting firms supply homogeneous products, market demand being

$$p = a - q_1 - q_2 \ . \tag{1}$$

Firm i's constant marginal cost is given by $c_i = c - x_i - \beta_j x_j$, where x_i is the R&D investment of firm i in cost reducing activities, and parameter $\beta_j \in [0,1]$ measures the amount of spillover from firm j to firm i. The R&D cost function of each firm is $K_i(x_i) = \frac{1}{2}\gamma(1+\beta_i)x_i^2$. Observe that the spillover to firm j enters the cost function of firm i so as to make it costly to the latter to transmit knowledge to the rival.[2] The profit function looks as follows:

$$\pi_i = (a - q_i - q_j - c + x_i + \beta_j x_j)q_i - \frac{\gamma}{2}(1+\beta_i)x_i^2 \ . \tag{2}$$

As shown by Amir (1998; see Hinloopen, 1997, for computational details), this setting encompasses both d'Aspremont and Jacquemin (1988) and Kamien, Muller and Zang (1992).[3]

We will examine the following cases:

- A symmetric duopoly where x_i and q_i are both set simultaneously, with x_i being chosen either cooperatively or noncooperatively, while q_i is always set noncooperatively.[4]

- An asymmetric duopoly with a dominant firm at the market stage. Here, R&D efforts are chosen noncoperatively and simultaneously, while the market stage is played *à la* Stackelberg.

In both cases, we will investigate the bearings on firms' performance as well as on social welfare of joint vs independent ventures. By this we mean that we are going to model explicitly firms' choices concerning the size of spillover β_i. Notice that the profit function (2) of firm i is, respectively, linear and increasing in β_j, and linear and decreasing in β_i. This makes it possible to establish that it is in the interest of each firm to set $\beta_i = 0$ (respectively, $\beta_i = 1$) if firms choose independent ventures (resp., if the set up a joint venture).[5]

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[2] In Amir (1998), symmetric spillovers are considered from the outset, so that the R&D cost function is $K_i(x_i) = \frac{1}{2}\gamma(1+\beta)x_i^2$. Alternatively, spillover effects may materialise under product innovation, via the demand functions (see Lambertini and Rossini, 1998; Lambertini *et al.*, 1998).

[3] For the strategic relevance of endogenous spillovers in R&D races, see De Fraja (1993).

[4] The possibility that firms cooperate at the market stage is considered both in d'Aspremont and Jacquemin (1988) and in Amir (1998). We say "cooperate" rather than "collude" because cartel stability is not characterised in either of these papers.

[5] The endogenous formation (and the optimal size) of coalitions, i.e., R&D joint ventures, is investigated by Yi and Shin (2000) in a model with n firms.

2.1 Cournot-Nash competition

We consider here the case where the market stage is played simultaneously. Proceeding by backward induction, the market stage is solved first for given values of x_i and β_i. The first order conditions (FOCs) are:

$$\frac{\partial \pi_1}{\partial q_1} = a - 2q_1 - q_2 - c + x_1 + \beta_2 x_2 = 0 \tag{3}$$

$$\frac{\partial \pi_2}{\partial q_2} = a - 2q_2 - q_1 - c + x_2 + \beta_1 x_1 = 0 \tag{4}$$

whose solution yields the Cournot-Nash equilibrium quantities:

$$q_1^N = \frac{a - c + (2 - \beta_1)x_1 - (1 - 2\beta_2)x_2}{3} \tag{5}$$

$$q_2^N = \frac{a - c + (2 - \beta_2)x_2 - (1 - 2\beta_1)x_1}{3} \tag{6}$$

Plugging (5) and (6) into the profit functions (2) and simplifying, one gets the relevant objective function of firm i at the second stage of the game:

$$\pi_i = \frac{\left[a - c + (2 - \beta_i)x_i - (1 - 2\beta_j)x_j\right]^2}{9} - \frac{\gamma(1 + \beta_i)x_i^2}{2} \tag{7}$$

Suppose first that firms can perfectly control the reciprocal spillover effects, as in Poyago-Theotoky (1999). Observe that π_i is parabolic and convex in β_i. In particular, $\partial^2 \pi_i / \partial \beta_i^2 = 2x_i^2/9 > 0$ for all admissible levels of the firm's R&D effort.[6] Hence, we can only expect corner solutions in the second stage, where firms decide over the extent of the reciprocal spillovers. This leads to

Lemma 1 *Assume firms can perfectly control the reciprocal spillovers. If so, firms' choices as to their reciprocal spillovers are as follows:*

(i) ***Independent Ventures.*** *When firms do not cooperate in terms of information sharing, then* $\beta_i = 0\ \forall i$.

(ii) ***Joint Venture.*** *If firms set up a joint venture at the second stage, then* $\beta_i = 1\ \forall i$.

Consider now the first stage, where firms decide upon their R&D efforts x_i. First, examine the situation where firms play noncooperatively in the research stage.

[6] Poyago-Theotoky (1999) assumes that the costs of innovation are $(\gamma x_i^2)/2$. However, this does not affect the sign of $\partial \pi_i / \partial \beta_i$, which is always negative.

2.1.1 Noncooperative R&D activities

For generic spillover levels, the relevant FOC for firm i is:

$$\frac{\partial \pi_i}{\partial x_i} = \frac{2(2-\beta_i)\left[a-c+(2-\beta_i)x_i-(1-2\beta_j)x_j\right]}{9} - \gamma(1+\beta_i)x_i = 0 \qquad (8)$$

Imposing $\beta_i = \beta_j = \beta$ and solving for symmetric effort levels $x_i = x_j$ yields:[7]

$$x^N = \frac{2(2-\beta)(a-c)}{(1+\beta)(9\gamma+2\beta-4)} \qquad (9)$$

Following Poyago-Theotoky (1999), one may endogenise the size of the spillover, depending upon the organisational design of R&D activity. Under independent ventures (IV), setting $\beta_i = 0$ and imposing the obvious symmetry condition $x_i = x_j$ yields optimal R&D investment $x^N(IV) = 4(a-c)/(9\gamma-4)$, which is acceptable for all $\gamma > 4/9$.[8] Equilibrium outputs are $q^N(IV) = 3(a-c)\gamma/(9\gamma-4)$. The corresponding equilibrium profits, consumer surplus and social welfare are $\pi^N(IV) = (a-c)^2\gamma(9\gamma-8)/(9\gamma-4)^2$; $CS^N(IV) = 18(a-c)^2\gamma^2/(9\gamma-4)^2$; and $SW^N(IV) = 2\pi^N(IV) + CS^N(IV) = 4(a-c)^2\gamma/(9\gamma-4)$.

Under joint venture (JV), setting $\beta_i = 1$ and imposing again symmetry $x_i = x_j$ yields individual equilibrium R&D effort $x^N(JV) = (a-c)/(9\gamma-2)$, which is acceptable for all $\gamma > 2/9$. The equilibrium per-firm production level of the final good is $q^N(JV) = 3(a-c)\gamma/(9\gamma-2)$. The corresponding equilibrium profits, consumer surplus and social welfare are $\pi^N(JV) = (a-c)^2\gamma(9\gamma-1)/(9\gamma-2)^2$; $CS^N(JV) = 18(a-c)^2\gamma^2/(9\gamma-2)^2$; and $SW^N(JV) = 2\pi^N(JV) + CS^N(JV)$ $= 2(a-c)^2\gamma(18\gamma-1)/(9\gamma-2)^2$.

Comparing $x^N(IV)$ and $x^N(JV)$ produces the following:

Remark 1 *If the R&D cost parameter $\gamma \in (2/9, 4/9)$, firms may activate a joint venture while they cannot choose independent ventures.*

2.1.2 R&D cartel

Consider now the case of joint profit maximization in the R&D effort levels. The cartel problem, defined for generic spillover levels, is:

$$\max_{x_1,x_2} \Pi^C = \pi_1+\pi_2 = \frac{1}{9}\sum_{i=1}^{2}[a-c+x_i(2-\beta_i)-x_j(1-2\beta_j)]^2 - \frac{\gamma}{2}\sum_{i=1}^{2}(1+\beta_i)x_i^2 \quad (10)$$

[7] For a case where the global maximum may involve asymmetric R&D investments at the first stage, see Salant and Shaffer (1998).

[8] Asymptotic stability requires that

$$\left(\frac{\partial^2 \pi_i}{\partial x_i^2}\right)^2 - \left(\frac{\partial^2 \pi_i}{\partial x_i \partial x_j}\right)^2 \geq 0\,.$$

in an open neighbourhood of the equilibrium. For the sake of brevity, we omit the related calculations. See Qiu (1997).

yielding the following FOC:

$$\frac{\partial \Pi^C}{\partial x_i} = \frac{(2+2\beta_i)(a-c) + x_i[10 - 16\beta_i + 10\beta_i^2 - 9\gamma(1+\beta_i)]}{9} + \tag{11}$$
$$+ \frac{-2x_j[4 - 5(\beta_i + \beta_j) - 4\beta_i\beta_j]}{9} = 0 \; .$$

Under the reasonable assumption that $\beta_i = \beta_j = \beta$, the symmetric solution to (11) is:

$$x_i = x_j = x^C = \frac{2(a-c)}{9\gamma - 2\beta - 2} \; . \tag{12}$$

Then, substituting and symplifying yields individual output levels $q^C = 3(a-c)\gamma/(9\gamma-2\beta-2)$ and cartel profits $\pi^C = (a-c)^2\gamma/(9\gamma-2\beta-2)$. Consumer surplus at the cooperative equilibrium amounts to $CS^C = 18(a-c)^2\gamma^2/(9\gamma-2\beta-2)^2$, and finally social welfare is $SW^C = 4(a-c)^2\gamma(9\gamma-\beta-1)/(9\gamma-2\beta-2)^2$. Setting $\beta = 0$ or $\beta = 1$, alternatively, yields the relevant equilibrium magnitudes in the cases of independent ventures or joint ventures, respectively. This allows us to state the following proposition (see Amir, 1998, Appendix):

Proposition 1 *Compare the R&D effort levels* x^N *and* x^C *:*
(i) Under independent ventures, set $\beta = 0$ *and assume* $\gamma > 4/9$ *in order for* $x^N(JV)$ *and* $x^C(JV)$ *to be both admissible. Then,* $x^N(JV) > x^C(JV)$.
(ii) Under joint venture, set $\beta = 1$ *and assume* $\gamma > 2/9$ *in order for* $x^N(IV)$ *and* $x^C(IV)$ *to be both admissible. Then,* $x^N(IV) < x^C(IV)$.

A firm's individual preferences over the alternative arrangements for innovative activities are summarised by:

Proposition 2 $\pi^C(JV) > \pi^N(JV) > \pi^C(IV) > \pi^N(IV)$ *for all* $\gamma > 4/9$.

Proposition 2 establishes that, overall, the joint venture clearly dominates independent ventures from the individual firm's viewpoint. Instead, the convenience of cooperation at the first stage is ambiguous, in that the choice of noncooperative research efforts dominates cooperation if the former perspective is accompanied by a joint venture while the second combines with independent ventures. Observe that the chain of inequalities in the above proposition fails to hold if $\gamma \in (2/9, 4/9)$, where only independent ventures are admissible while the joint venture is not.

Social preferences remain to evaluate. This is done in the following:

Proposition 3 $SW^C(JV) > SW^N(IV) > SW^N(JV) > SW^C(IV)$ *for all* $\gamma > 4/9$.

Finally, propositions 2 and 3 produce the following relevant corollary:

Corollary 1 *The combination of R&D cooperation and joint venture appears as the best option from both the individual and the social standpoint.*

2.2 Cournot-Stackelberg competition

Here, we characterise the situation where there exists a dominant firm. To formalise this idea, we suppose that one firm takes the lead at the third stage of the game, and the rival follows. As in 2.1.1, the solution concept for the first and the second stage is the simultaneous Nash equilibrium.[9] Assume firm 1 plays the leader's role. Again, the three-stage game is solved by backward induction. The leader's problem consists in:

$$\max_{q_1} \pi_1 = (a - q_1 - q_2 - c + x_1 + \beta_2 x_2) q_1 - \frac{\gamma}{2}(1 + \beta_1) x_1^2 \tag{13}$$

under the constraint represented by the follower's reaction function:

$$q_2 = \frac{a - c - q_1 + \beta_1 x_1 + x_2}{2} \,. \tag{14}$$

The leader's optimum at the market stage is then easily calculated:

$$q_1^{SL} = \frac{a - c - \beta_1 x_1 - x_2}{2} + x_1 - \beta_2 x_2 \,. \tag{15}$$

Superscript SL stands for *Stackelberg leader*. The resulting profit functions at the second stage are:

$$\pi_1 = \frac{[a - c + (2 - \beta_1) x_1 + (2\beta_2 - 1) x_2]^2}{8} - \frac{\gamma(1 + \beta_1) x_1^2}{2} \,; \tag{16}$$

$$\pi_2 = \frac{[a - c - (2 - 3\beta_1) x_1 + (3 - 2\beta_2) x_2]^2}{16} - \frac{\gamma(1 + \beta_2) x_2^2}{2} \,, \tag{17}$$

where superscript SF stands for *Stackelberg follower*. Here, the analysis of the first two stages is more involved than under Cournot-Nash behaviour, due to the asymmetry associated with the above Stackelberg solution at the market stage.

Suppose first that spillovers β_i are exogenously given. If so, firms proceed to optimise w.r.t. R&D efforts to obtain $x_1^{SL}(\beta_1, \beta_2)$ and $x_2^{SF}(\beta_1, \beta_2)$.[10] It can be established that $x_1^{SL}(\beta_1, \beta_2) > x_2^{SF}(\beta_1, \beta_2)$ for all

$$\beta_1 \in \left[0, \frac{(2\beta_2 + 1)\beta_2 - 6 - 5\gamma + \sqrt{\Theta}}{2(2\beta_2 - 3)}\right) \,, \tag{18}$$

where

$$\Theta = [5\gamma - \beta_2(2\beta_2 + 1) + 6]^2 - 4(2\beta_2 - 3)\,[2(2\beta_2 - 3\gamma - 3) - \gamma] \,. \tag{19}$$

[9] Here, we focus on noncooperative behaviour throughout the three stages.

[10] The expressions for $x_1^{SL}(\beta_1, \beta_2)$ and $x_2^{SF}(\beta_1, \beta_2)$ are omitted for brevity. They are available upon request.

Conversely, $x_1^{SL}(\beta_1, \beta_2) < x_2^{SF}(\beta_1, \beta_2)$ for all values of β_1 higher than the upper bound of the interval specified in (18). Therefore, given generic spillover levels, the comparison between firms' R&D investments yields amiguous results if Stackelberg competition at the third stage is considered.[11]

However, this ambivalence vanishes if spillovers are endogenous. It can be quickly checked that, under strictly noncooperative behaviour, both firms find it profitable to reduce spillovers as much as possible, i.e., $\partial\pi_i/\partial\beta_i < 0 \; \forall i$. As an illustration, suppose firms can perfectly control spillovers. Since $\partial\pi_i/\partial\beta_i < 0$, at the second stage both firms set $\beta_i = 0$. Hence, the relevant objective functions at the first stage become:

$$\pi_1 = \frac{(a - c + 2x_1 - x_2)^2}{8} - \frac{\gamma x_1^2}{2}\,; \tag{20}$$

$$\pi_2 = \frac{(a - c - 2x_1 + 3x_2)^2}{16} - \frac{\gamma x_2^2}{2}\,. \tag{21}$$

The FOCs are:

$$\frac{\partial\pi_1}{\partial x_1} = \frac{a - c + 2(1-\gamma)x_1 - x_2}{2} = 0 \tag{22}$$

$$\frac{\partial\pi_2}{\partial x_2} = \frac{3(a - c) - 6x_1 + (9 - 8\gamma)x_2}{4} = 0 \tag{23}$$

yielding

$$x_1^{SL} = \frac{2(a-c)(2\gamma - 3)}{8\gamma^2 - 17\gamma + 6}\,;\; x_2^{SF} = \frac{3(a-c)(\gamma - 2)}{8\gamma^2 - 17\gamma + 6} \tag{24}$$

as the equilibrium R&D investment. Observe that x_1 and x_2 are both positive if $\gamma > 2$. Obviously, this constraint comes from the follower's solution.[12] Moreover, notice that $x_1^{SL} > x_2^{SF}$. Then, the above discussion, together with the comparison between (24) and (9) suffice to derive the following:

Proposition 4 *When the market stage is a Stackelberg game, then*

(i) If spillovers are exogenous or imperfectly controlled by firms, the market leader invests more than the follower if the spillover from the leader to the follower is sufficiently low.

(ii) If firms control their respective spillover levels, the market leader invests less than under the Nash equilibrium solution for all admissible values of the relevant parameters. The opposite holds for the market follower.

Evaluating the overall effort of the industry under the Stackelberg solution, against the corresponding magnitude observed under the Nash solution, we obtain the following:

[11] This result is broadly in line with previous literature on asymmetric R&D races (see Grossman and Shapiro, 1987; Delbono and Denicolò, 1991, *inter alia*).

[12] Second order conditions are met for all $\gamma > 9/8$.

Proposition 5 *Industry R&D effort is larger under the Nash equilibrium than under the Stackelberg equilibrium for all* $\gamma > 2$.

This can be entirely imputed to the lower incentive for the leader to invest in process innovation, due to the fact that this firm trades off the possibility of enhancing her own profits through market leadership against the alternative consisting in a costly commitment. Observe that the above statement is true *a fortiori* when $\gamma \in (0, 2]$, as in such a range the Stackelberg equilibrium is inadmissible.

2.3 Discussion

The above analysis has been carried out under the assumption that technological spillovers be entirely under the firms' control. However, in real-world situations we may not expect firms to be able to perform such a complete mastering of the flow of information produced by their R&D activities. For example, illegal information acquisition and/or skilled labour mobility may generate some degree of spillovers escaping firms' control.

Hence, in general, we may formulate the following:

Proposition 6 *(Amir, 1998) For all acceptable values of* γ, *we have that*
(i) $x^N > x^C$ *for all* $\beta \in [0, 1/2)$, *and*
(ii) $x^N < x^C$ *for all* $\beta \in (1/2, 1]$.

This amounts to saying that cooperation in R&D entails an effort-saving effect if and only if technological spillovers are low enough. In the opposite case, cooperation produces higher R&D efforts as compared to the noncooperative setting, because the maximisation of joint profits allows firms to extract more consumer surplus and thus leads them to invest a larger amount of resources (see also d'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992; Suzumura, 1992). However, this result drastically depends upon firms' ability to control endogenously the extent of externalities. In general, the following holds:

Proposition 7 *Since* $\partial\Pi^C/\partial\beta_i > 0$ *and* $\partial\pi_i^J/\partial\beta_i < 0$, $J = N, SF, SL$, *spillovers can be expected to be higher when firms set up an R&D cartel, as compared to all other situations where they compete in R&D.*

The above statement is a qualitative prediction suggesting that cooperation may boost the exchange of information between firms (and conversely for the case of noncooperative behaviour).

3 Data

In order to provide empirical evidence in support of some of the theoretical hypotheses discussed in previous sections, we use a micro-aggregated version of the first Community Innovation Survey (CIS) database provided by Eurostat. The CIS project was launched in 1991 to store micro data on innovative activities from all member states of the European Union (EU) in one common, harmonised data base. As a firm-based survey of innovation, it provides information on innovative output, determinants of innovation, barriers to innovation, innovative efforts, and innovative results. In this connection, it can be used to overcome the most frequent problems arising from the adoption of traditional indirect measures of innovation, such as R&D investments, number of patents, and technological balance of payments.

Due to confidentiality reasons, the original data collected for year 1992 in each of the participating countries were micro-aggregated by Eurostat using different techniques according to the nature of the variables. Three micro-aggregation procedures were applied in the cases of quantitative, ordinal, and nominal variables, respectively: individual ranking, individual ranking with "snake", and classification by "similitude". Application of the individual ranking method to quantitative variables required the primary variables to be ranked in increasing order, and individual observations to be grouped by three and then replaced with the cluster arithmetic mean. Whereas all the metric variables were micro-aggregated independently, ordinal variables were grouped into appropriate segments, and then ranked accordingly. In particular, once a segment of at least two ordinal variables had been identified, an arbitrary aggregation path (the snake) was chosen. The first three observations that the snake encountered were grouped together and therefore the original values were replaced with the median of the group. Then, the same procedure applied to the next three and so on. In the case of nominal variables, a simple method of grouping similar observations according to a particular segment was used: the most similar three observations were grouped together and the original values replaced by the cluster mode.[13]

Thus, in the present paper, we use micro-data dealing with "pseudo-firms" obtained through a standardised micro-aggregation procedure. In particular, the CIS database is employed in relation to four industries in manufacturing for five EU countries: Belgium, Denmark, Germany, Italy, and Norway. The industries were selected on the basis of their general technological features, according to the commonly used taxonomy suggested by Pavitt (1984). We chose the following types of industries: *scale intensive* (Textiles), *supplier dominated* (Clothing), *science based* (Chemicals), and *specialised supplier* (Mechanical engineering). As far as the variables are concerned, all the relevant information refers to 1992, with "R&D cooperation" denoting (pseudo)firms involved in any kind of formal

[13] It is worth noting that the observations grouped together had a very close distribution.

or informal R&D project with other (pseudo)firms, and the ECU's amounts for "R&D expenditures" and "R&D expenditures per employee" (as a proxy for R&D intensity) expressed in current 1992 ECU. The distribution of (pseudo)firms by industry and country is reported in table 1.

Table 1. *Number of (pseudo)firms by industry and country*

	Textiles	**Clothing**	**Chemicals**	**Mech. Eng.**	**Total**
BEL	498	205	327	326	1356
DK	69	4	106	349	528
GER	2092	891	2350	10589	15922
ITL	919	371	552	1969	3811
NOR	12	14	34	117	177
Total	3590	1485	3369	13350	21794

The original survey was carried out on a sample of enterprises, representative of the whole frame population. Accordingly, before carrying out any analysis, it was necessary to take into account the grossing up factors (or weighting factors). To this purpose, each observation was multiplied for the corresponding weighting factor.[14]

4 Empirical results

Due to strong data constraints, we could only test directly Propositions 4, 5, 6 and 7, under the assumption that spillovers are taken as exogenous.

As stated in Propositions 4 and 5, Stackelberg leaders are expected to have a lower innovative effort than other firms. For the purposes of the empirical analysis, we identified Stackelberg leaders by computing for each industry in each country a standard measure of concentration: the Linda index. This differs from the most common measures of concentration for its usefulness in identification of the "oligopoly threshold".

The Linda index is based on the following relation:

$$Q_i = \frac{A_i}{i} \Big/ \frac{A_K - A_i}{K - i} \tag{25}$$

where firms are ordered by the decreasing value of their market share Q, with A_i denoting the total market share of the first i firms among the K largest ones. In this relation, K is a number bounded between 2 and N, which in turn denotes the total number of firms.

[14]Estimations carried without weighting factors provide results consistent with those presented here. They are available on request from the authors.

The Linda index is then computed as:

$$L = \frac{1}{K(K-1)} \cdot \sum_{i=1}^{K-1} Q_i \tag{26}$$

In this way, a measure of concentration (L) obtains, conditional upon the value chosen for K. Accordingly, in order to identify the oligopoly threshold (if it does exist) in each market, a set of Linda indeces must be computed: L_2 for $K = 2$, L_3 for $K = 3$, L_4 for $K = 4$, and so on.

When it is identified, the first discontinuity in the computed values of the Linda index denotes the set of K firms operating in the oligopoly area. In other words, when the Linda index computed for $K + 1$ firms is higher than that computed for K firms, then K represents the oligopoly threshold. In this paper, we compute market shares as ratios between a firm's sales and total sales in the industry, and we do this separately for each country. Firms inside the oligopoly area are taken as Stackelberg leaders, whereas those outside are considered as Stackelberg followers.A summary is given in Table 2.

Table 2. *Number of market leaders by country and industry*

	Belgium	**Denmark**	**Germany**	**Italy**	**Norway**	**Total**
Textiles	132	23	418	0	5	578
Clothing	169	0	226	20	0	415
Chemicals	15	34	496	0	4	549
Mechanichal Eng.	7	7	0	0	23	37

To test propositions 4 and 5 empirically, we use (Table 3) a simple analysis of variance (ANOVA) test for the differences in the mean values of R&D effort between two groups of (pseudo)firms: alleged Stackelberg leaders and alleged Stackelberg followers. We tested the level of significance of such differences using both the total amount of firms' R&D expenditures and the proxy for R&D intensity.

Table 3. *Empirical test of Propositions 4 and 5*
Market leaders have a lower incentive to invest in R&D

		Type of fims	Mean	Std Dev	N. cases	ANOVA
Text.	R&D	All	127.520	990.0780	3590	
		Followers	70.3158	298.7992	3012	63.5842***
		Leaders	425.8570	2351.5280	577	
	R&D_EMPL	All	1.4664	2.9249	3590	
		Followers	1.2552	2.3163	3012	100.2746***
		Leaders	2.5677	4.8769	577	
Cloth.	R&D	All	927.6806	4539.4189	1485	
		Followers	76.5973	1080.0691	1070	148.1880***
		Leaders	3125.7671	8013.6750	414	
	R&D_EMPL	All	2.1103	8.1138	1485	
		Followers	0.7440	4.3991	1070	117.2759***
		Leaders	5.6391	12.9964	414	
Chem.	R&D	All	3751.8390	36262.7565	3339	
		Followers	1062.7658	6612.8472	2790	95.8840***
		Leaders	17406.3445	86939.2089	549	
	R&D_EMPL	All	15.2206	178.4924	3339	
		Followers	17.0658	195.2102	2790	1.8124
		Leaders	5.8510	6.5240	549	
Mech. Eng.	R&D	All	681.6399	4867.5209	13350	
		Followers	661.0321	4790.4473	13313	86.9880***
		Leaders	8125.0784	15607.2925	37	
	R&D_EMPL	All	7.7654	105.7435	13348	
		Followers	7.7740	105.8893	13311	0.0319
		Leaders	4.6591	5.8409	37	

***. Significant at 95% level of confidence

With the first measure of innovative activity, the result predicted by the theory is rejected in all industries: Stackelberg leaders invest in R&D more than Stackelberg followers. This may suggest that the extent, if any, to which firms control spillovers is relatively low. More controversial findings are found when using the measure for R&D intensity: indeed, for both chemicals and mechanical engineering - namely, the two industries that, according to their general technological features, are likely to be more clearly committed to own R&D - it turns out that Stackelberg leaders invest in R&D less than Stackelberg followers, but the differences in the mean values are not statistically significant. Since R&D

intensity is the most reliable measure of a firm's involvement in innovative activities, these results can be taken as a partial corroboration of the hypothesis presented in Propositions 4 and 5 above.

Table 4. *Empirical test of Proposition 6*
R&D cooperation leads to a higher R&D investment

		Type of fims	Mean	Std Dev	N. cases	ANOVA
Text.	R&D	All	127.5120	990.0786	3590	
		R&DCoop NO	126.7517	1070.9732	3059	0.0122***
		R&DCoop YES	131.8924	141.9000	531	
	R&D_EMPL	All	1.4664	2.9249	3590	
		R&DCoop NO	1.0684	2.8235	3059	428.52906***
		R&DCoop YES	3.7591	2.3991	531	
Cloth.	R&D	All	927.6818	4539.4218	1485	
		R&DCoop NO	854.2934	4373.4341	1439	12.3034***
		R&DCoop YES	3236.4350	7936.8168	46	
	R&D_EMPL	All	2.1103	8.1139	1485	
		R&DCoop NO	1.9928	7.7837	1439	9.8529***
		R&DCoop YES	5.8063	14.8863	46	
Chem.	R&D	All	3751.8367	36262.7403	3339	
		R&DCoop NO	2979.6535	37059.6263	2863	9.1226***
		R&DCoop YES	8393.2415	30671.6717	476	
	R&D_EMPL	All	15.2206	178.4925	3339	
		R&DCoop NO	16.1614	192.7407	2863	0.5575
		R&DCoop YES	9.5656	6.3467	476	
Mech. Eng.	R&D	All	681.6399	4867.5209	13350	
		R&DCoop NO	540.5371	4148.4142	11681	78.9763***
		R&DCoop YES	1669.2057	8245.7182	1669	
	R&D_EMPL	All	7.7654	105.7435	13348	
		R&DCoop NO	8.0046	112.9907	11679	0.4777
		R&DCoop YES	6.0919	9.2985	1669	

***. Significant at 99% level of confidence

As stated in proposition 6(ii), firms involved in R&D cooperation are expected to exhibit higher levels of R&D investment. To test this theoretical prediction empirically, we employ again the ANOVA test for the differences in the mean values of R&D effort in the cases of (pseudo)firms who are involved in R&D cooperation and (pseudo)firms who are not.

Concerning the cases of textiles[15] and clothing (Table 4), the empirical test supports the hypothesis that firms involved in R&D cooperation display a higher level of R&D effort, in terms of both R&D expenditures and R&D intensity. With respect to chemicals and mechanical engineering, R&D intensity is instead lower for firms who are involved in cooperative R&D (although the difference is not statistically significant), whereas R&D expenditures are significantly higher for co-operating firms. Given the specific features of the overall innovation process in each industry, the results emerging from the *scale intensive* (Textiles) and the *supplier dominated* (Clothing) industries[16] suggest that when own R&D is not as relevant as other sources of technological inputs (e.g., knowledge embodied in new machinery and technical equipment, learning by doing, etc.), cooperative R&D is a way to enhance the commitment, and improve the ability, to carry out own R&D. Conversely, in industries which rely mostly upon own R&D as a source of innovation, like chemicals and mechanical engineering, rival firms are more likely to be involved in formal and informal trading of proprietary know-how.

Table 5. *Empirical test of Proposition 7*
Cooperation enhances the level of R&D spillovers

		Type of firms	Mean	Std Dev	N. cases	ANOVA
		All	10.5100	0.5760	3590	
	Text.	R&DCoop NO	10.5325	0.6072	3059	31.9180***
		R&DCoop YES	10.3802	0.3157	531	
		All	10.6226	1.7745	1474[a]	
	Cloth.	R&DCoop NO	10.5941	1.7954	1428	11.9405***
Amount of		R&DCoop Yes	11.5117	0.0898	46	
Spillovers		All	14.2883	0.5807	3339	
	Chem.	R&DCoop NO	14.2662	0.5793	2863	29.3018***
		R&DCoop YES	14.4211	.05719	476	
		All	13.8600	0.5685	13350	
	Mech.	R&DCoop NO	13.8480	0.5714	11681	41.8309***
	Eng.	R&DCoop YES	13.9441	0.5402	1669	

***. Significant at 99% level of confidence; a. The difference is due to missing values

In proposition 7 above, we assert that involvement in R&D cooperation may boost the exchange of information between firms, thereby enhancing the level of R&D spillovers. According to the results shown in Table 5 - again obtained by running the ANOVA test for the differences in the mean values of R&D effort -

[15] Even if, in the case of R&D expenditures, the difference is not statistically significant.
[16] Which have been shown by Pavitt (1984) to rely almost exclusively (supplier dominated) and significantly (scale intensive) on external sources of innovation.

Proposition 7 is confirmed in three industries out of four: with the sole exception of the textile industry,[17] (pseudo)firms involved in R&D cooperation benefit from a higher level of spillovers.

5 Concluding remarks

We have investigated several aspects of firms' R&D activity, under the assumption that quantity-setting firms may control technological externalities. We have considered both Cournot-Nash and Cournot-Stackelberg behaviour. Under Cournot-Nash behaviour at the market stage, we have addressed an issue that have been largely debated in the existing literature, namely, whether cooperation (either as a joint venture or as an R&D cartel) entails a reduction in the well known effort duplication effect associated with strictly noncooperative behaviour. Under Cournot-Stackelberg behaviour, we have investigated the incentives to invest in R&D when firms are asymmetric. The empirical analysis does not provide support to the idea that firms control spillovers. Indeed, it appears that spillovers are an environmental feature conditioning firms' efforts, rather than the opposite. Moreover, the cost-saving effect associated to joint ventures or R&D cartels is confirmed for industries where firms rely mainly upon own R&D as a source of innovation. Finally, cooperating in R&D increases the transmission of knowledge, thereby enhancing spillovers.

[17] Although their differences are statistically significant, the absolute levels of the mean values are very close to each other.

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