Spillover and RD Incentives under Incomplete Information in a Duopoly Industry

Chatterjee, Rittwik and Chattopadhyay, Srobonti and Kabiraj, Tarun

Centre for Studies in Social Sciences, Calcutta, Vidyasagar College for Women, Kolkata, Indian Statistical Institute, Kolkata

1 June 2017

Spillover and R&D Incentives under Incomplete Information in a Duopoly Industry

Rittwik Chatterjee*

Srobonti Chattopadhyay†

Tarun Kabiraj‡

Abstract

Spillover of R&D results in oligopolistic industries may affect the R&D decisions of firms. How much a newly developed technology by a firm gets spilled over to its rival firms may or may not be observable by the concerned firm. This paper considers a two stage game involving two firms. In the first stage the firms decide whether to invest in R&D and in the next stage they compete in a Cournot duopoly market. The R&D incentives of firms are compared under alternative assumptions of complete and incomplete information scenarios involving general distribution function of types. The results indicate that the impact of availability of more information regarding rival's ability to benefit from spilled over knowledge on R&D activities of firms is ambiguous.

Keywords: R&D incentives, Duopoly, Asymmetric information, Spillover, Type distribution.

JEL Classification: D43, D82, L13, O31.

*Centre for Studies in Social Sciences, Calcutta, **Email:** rittwik@gmail.com

†Vidyasagar College for Women, Kolkata, **Email:** srobonti@gmail.com

‡Indian Statistical Institute, Kolkata, **Email:** tarun@isical.ac.in

1 Introduction

Spillover of R&D results is a common phenomenon in industries. Most commonly, spillover is perceived as a leakage of the R&D results of a firm, voluntarily or involuntarily, to other firms in the same or other industries. The possibility of knowledge spillovers affect the R&D decisions of firms. In presence of spillovers, firms tend to underinvest in R&D (as noted by Katz (1986), d'Aspremont and Jacquemin (1988), Kamien et.al. (1992), and Suzumura (1992)). This is why very often firms get involved in race for patents in order to secure their R&D output. Patent race has been widely studied in R&D literature (for example, Shapiro (1985), Baye and Hoppe (2003), Baker and Mezetti (2005) etc.). Another way to address the problem of non-appropriability of R&D knowledge in presence of spillovers lies in Research Joint Ventures (RJVs). As shown by d'Aspremont and Jacquemin (1988), RJV enhances level of R&D investments when spillover rates are high.

However, it is not always possible to get patent or copyright for innovations. Neither it is always possible to have RJVs. Under such situations firms decide whether to invest in R&D depending on what information they have about their rivals' abilities of benefiting from spillovers of their R&D knowledge. This paper makes an attempt to study the R&D incentives of firms in a duopoly framework under different information scenarios where spillover of R&D knowledge is involuntary and automatic. We term the proportion of the R&D output that gets spilled over to any firm from its rival firm its spillover parameter. All firms in our framework are always aware of their own spillover parameters. But a firm may or may not know the spillover parameter os its rival since the ability to benefit from spillover of knowledge from other sources depends largely on endogenous factors of a firm and these factors may not be observable to outsiders. Accordingly we may have two alternative information structures. When every firm knows its own as well as its rival's spillover parameters, we have a complete information framework. When a firm can only observe its own spillover parameter, we are in an incomplete information scenario. In case of incomplete information, thus, the spillover parameters constitute types of the firms. This paper considers general distribution function of types.

Impact of spillovers on R&D incentives is quite well looked at in the literature. Reinganum (1981) shows how if "the value of adopting a cost-reducing, capital embodied process innovation declines with the number of firms", then the adopting firms are induced to use newer technologies in a sequence and thus the knowledge gets diffused over time. Grilliches (1992) emphasises the importance of R&D spillovers with supportive empirical evidence. Mookherjee and Ray (1991) considers the diffusion of the latest technology developed by a dominant firm to competitive fringe firms for both price and quantity competitions in the product market. In their model, Schumpetrian cycles of innovation and diffusion are observed in the product market when there is price competition in the product market. Their result shows that the increase in the rate of diffusion enhances the pace of innovation up to a certain pint and has ambiguous effect on R&D incentives for price competition and the results are reversed for quantity competition. Harhoff (1991) elaborates a scenario involving a monopoly supplier of intermediate goods to an oligopoly industry, where the monopoly supplier deliberately allows spillover of its R&D outputs which substitutes the R&D efforts of the competing firms in the oligopoly industry. This leads to an expansion in the output of oligopoly industry thus raising the demand for the input supplied by the monopoly firm and this is how the monopoly firm benefits indirectly despite the absence of a market for R&D information. De Bondt (1997) explains how spillover possibilities discourage R&D due to free riding by rivals. However, De Bondt (1997) also discusses how spillover can create incentives for R&D as R&D efforts by one firm induces other firms to undertake similar endeavours and thus all of them end up producing at lower costs leading to lower prices and therefore enhanced demand, which De Bondt (1997) formally calls "market expansion effect".

R&D incentives are also impacted on by prevailing market structures. De Bondt (1997) notes that R&D incentives are higher in oligopolistic market structures compared to bot the the extremes of perfect competition and monopoly. Matsumura et. al. (2013) consider a duopoly industry and find a no-monotone relationship between degree of competitiveness and R&D investment. Shibata (2014) extends the work of Matsumara et.al. (2013) by incorporating the possibility of R&D spillovers. The results show that for duopoly markets, non-cooperative R&D is preferred over cooperative R&D when spillovers are small (less than half), but for large spillovers (i.e. more than half) cooperative R&D is the more preferred mode.

R&D incentives under incomplete information is a relatively less trodden area. However, there are a few interesting works. Conti (2014) investigates the role of asymmetric information in context of RJVs in a duopoly market in presence of spillovers. Conti (2014) considers a situation where firms are symmetric initially, but they differ in terms of their R&D abilities leading to inter firm asymmetry after the R&D. Firms may not be able to observe the R&D ability of its rivals. In the concerned paper there is one sided private information, i.e. only one firm has private information about its R&D ability. In a recent work, Frick et.al. (2016) study a duopoly market where firms decide both R&D investment levels and entry time i.e. when to introduce the new product in the market in an incomplete information framework. Here, both the firms try to develop a prototype, and once it is developed, they decide when to to introduce the new product. The firms differ in terms of their R&D abilities and thus the earliest date at which a prototype can be created varies across firms. This earliest date is private information to every firm. Whichever firm succeeds in developing the prototype first takes away the whole profit. Observability of the rival's R&D activity plays no role in the decision regarding R&D investment in this model.

R&D incentives when spillover parameters are private information have not been explored. This paper makes an attempt to fill this gap in the literature by addressing this issue in a quite general framework.

The organisation of the paper is as follows. Section 2 discusses the model setup. sections 3 and 4 elaborate the complete information scenario in absence and presence of spillover respectively, section 5 elaborates on the incomplete information scenario, section 6 compares the threshold values of the spillover parameter (the types below these values only invest in R&D) under alternative information structures and section 7 concludes the paper.

2 Model Setup

We consider a Cournot duopoly. The firms are denoted by A and B. The inverse demand function of the market is given by $\max\{0, a - Q\}$, where $a > 0$ and Q is the aggregate output produced in the market. Firms have constant and positive marginal cost denoted by c.

Firms are deciding to invest in a cost reducing R&D. The cost of the R&D is H which is positive and is assumed to be equal for both the firms. If a firm undertakes the R&D then her marginal cost becomes $c - D$, where $0 < D < c$. We further assume $a > c + D$.

Suppose firm j invests in R&D but firm i does not; then a part of the R&D will diffused to firm i. The amount of spillover is denoted by d_i. So the marginal cost of the firm i after the spillover is $c - d_i$. Clearly $d_i \in [0, D]$ for all $i \in \{A, B\}$. We assume that d_i is distributed with the distribution function $F(\cdot)$ and continuous density function $f(\cdot)$ and has full support. Therefore, d_i also denotes the type of firm i and is private information to firm i in case of incomplete information. It is assumed that firm i knows its own type, before deciding on the R&D activity.

Some notations: $W := a - c$, $q(x) := \frac{W+x}{3}$, $\Pi(x) := q^2(x)$ and $\Psi(x) := \int_x^D y \frac{dF(y)}{1-F(x)}$[1]. Note that $q' > 0$, $\Pi'(x) = \frac{2}{3}q(x) > 0$, $\lim_{x \to D} \Psi(x) = D$[2] and $\Psi'(x) > 0$ when $x \in (0, D)$. Denote 'doing research' by R and 'no research' by N. Suppose firm A chooses to invest in research and firm B does not, then we denote profit (expected profit) of the firm A by $\Pi_A^{[RN]}$ ($E\Pi_A^{[RN]}$) and that of firm B by $\Pi_B^{[RN]}$ ($E\Pi_B^{[RN]}$). Similar notation will be used for other cases.

Our objective is to find out how the decision of performing the research is dependent on the type of a firm and the level of information available to it. So it is a two stage game. In the first stage each of the firms is deciding whether to invest in research. And in the second stage they are competing in the after-market.

[1]The average value of y given that y lies between x and D.
[2]The intuition is that $\Psi(x)$ must lie between x and D.

3 Complete information: No Spillover

If a firm invests in research then her marginal cost is $c - D$, otherwise it is c.

Lemma 3.1. *Following holds*

- *If none of them invests in research then each one has a profit of* $\Pi(0)$.
- *If both of them invest in research then each one has a profit of* $\Pi(D)$.
- *If firm i invests in research and firm j does not then the profit of firm i is* $\Pi(2D)$ *and the profit of firm j is* $\Pi(-D)$.

Remark 1. First, note that if the rival is not doing the research then it is always optimal for firm i to do the research iff $\Pi(2D) \geq \Pi(0) + H$, that is, iff $\frac{4(W+D)D}{9} \geq H$. Second, if the rival firm is doing the research then the firm i will do the research iff $\Pi(D) \geq \Pi(-D) + H$, that is, iff $\frac{4WD}{9} \geq H$.

Lemma 3.2. *Following holds*

- *Both of them will invest in research if* $\frac{4WD}{9} \geq H$.
- *None of the will invest in research if* $\Pi(2D) \leq H$.
- *Only one of them will invest in research if* $D^2 \geq \frac{9H}{4} - WD$[3].

4 Complete Information: With Spillover

We assume in this section that everything is common knowledge, including the types of the firms. Since we are considering duopoly, at equilibrium three cases can happen: (1) both the firms invest in R&D, (2) none of the firms invests in R&D and (3) one firm invests and the other does not. The lemma below summarizes the payoffs of a firm under different equilibrium situations.

Lemma 4.1. *Given two firms i and j, $i = A, B$, $j = A, B$ and $i \neq j$,*

[3] The model does not predict which of the firms will invest in research in this scenario.

a. If both of them have not invested in research then each of them gets

$$\Pi_i^{[NN]} = \Pi_j^{[NN]} = \Pi\,(0)$$

b. If both of them have invested in research then they both get

$$\Pi_i^{[RR]} = \Pi\,(D) - H$$

c. Suppose firm i does the research and firm j does not, then,

$$\Pi_i^{[RN]} = \Pi\,(2D - d_j) - H$$

and

$$\Pi_j^{[RN]} = \Pi\,(2d_j - D)$$

Remark. First, note that if the rival is not doing the research then it is always optimal for firm i to do the research iff $\Pi\,(2D - d_j) \geq \Pi(0) + H$, that is iff $d_j \leq 2D - \left(\sqrt{W^2 + 9H} - W\right)$[4]. Second, if the rival firm is doing the research then the firm i will do the research iff $\Pi\,(D) \geq \Pi\,(2d_i - D) + H$ that is iff $d_i \leq \frac{\sqrt{(W-D)^2 + (4WD - 9H)} - (W-D)}{2}$[5]. So a firm will definitely invest in research iff both her type as well as her rival's type is "sufficiently" small.

Note that if $H > \frac{4WD}{9}$ then both of the firms will never research simultaneously. In this case either none of them will invest in research or only one of them will invest in research[6]. In particular if $H \geq \frac{4(W+D)D}{9}$ then none of them will invest in research.

[4]The intution is that if the type of the rival is "sufficiently" small then by doing research the firm will earn higher profit, since the spillover effect is small.

[5]The intution is that if the type of the firm is "sufficiently" small then it is better for the firm to invest in research, since the spillover effect is small.

[6]Our model does not predict which one of the firms will invest in research in this particular case.

5 Incomplete Information

In this section we consider the incomplete information problem, hence we assume that d_i is private information to firm i. Note that each firm knows its type before it is deciding on R&D investment. Since R&D decision is taken at the first stage, therefore, at the beginning of the production stage, each firm can observe whether its rival has performed R&D or not. Suppose δ is the threshold value such that a firm will invest in research if and only if its type is less than or equal to δ. Given the cost of the research (i.e. M), our primary objective in this section is to find out δ.

Like the case of complete information we start our analysis by finding out the (expected) payoffs of firms under different situations. The three lemmas below derive the (expected) profits.

Lemma 5.1. *If both of them have not invested in research then each of them gets*

$$\Pi_A^{[NN]} = \Pi_B^{[NN]} = \Pi\left(0\right)$$

Lemma 5.2. *If both of them have invested in research then they both get*

$$\Pi_i^{[RR]} = \Pi\left(D\right) - M$$

Lemma 5.3. *Suppose firm A does the research and firm B does not.*

$$\Pi_A^{[RN]} = \Pi\left(2D - \Theta\left(\delta\right)\right) - M$$

and

$$\Pi_B^{[RN]} = \Pi\left(\frac{3d_B + \Theta\left(\delta\right)}{2} - D\right)$$

Proof. The expected profit of firm A is given by

$$(K + D)q_A - q_A^2 - q_A \int_{\delta}^{D} \frac{q_B(y)dF(y)}{1 - F\left(\delta\right)}$$

and that of firm B is

$$(K + d_B)\, q_B - q_B^2 - q_B q_A$$

The corresponding reaction functions are

$$(K + D) - 2q_A - \int_{\delta}^{D} \frac{q_B(y)dF(y)}{1 - F(\delta)} = 0$$

and

$$(K + d_B) - 2q_B - q_A = 0$$

Solving the two reaction functions stated above we get

$$q_A = q\,(2D - \Theta\,(\delta))$$

and

$$q_B = q\left(\frac{3d_B + \Theta\,(\delta)}{2} - D\right)$$

The rest of the proof is trivial. $\square$

If firm i is doing the research and she does not know whether firm j is doing the research or not, then her expected profit is

$$(1 - F(\delta))\Pi(2D - \Theta\,(\delta)) + F(\delta)\Pi(D) - M$$

On the other hand if firm i is not doing the research and she does not know whether firm j is doing the research or not, then her expected profit is

$$(1 - F(\delta))\Pi(0) + F(\delta)\Pi\left(\frac{3d_i + \Theta\,(\delta)}{2} - D\right)$$

Let $T(x;\delta)$ denote the gross opportunity gain from doing research when the type of the firm is x. Then $T(x;\delta)$ can be defined as

$$T\,(x;\delta) := (1 - F(\delta))\,[\Pi(2D - \Theta\,(\delta)) - \Pi(0)] + F(\delta)\left[\Pi(D) - \Pi\left(\frac{3x + \Theta\,(\delta)}{2} - D\right)\right]$$

.

Note that $T(x;\delta)$ is decreasing in x. Also,

$$T(0;0) = \Pi(2D - \Theta(0)) - \Pi(0)$$

and with slight abuse of notation let

$$T(D;D) := \lim_{x \to D} T(x) = 0$$

So $T(0;0) > T(D;D)$. Finally, δ must satisfy the following equation

$$T(\delta;\delta) = M$$

As stated above our objective is to find out δ as a function of M. However, note that till now there is nothing that tells us that for a particular M there will be a unique δ. The following lemma ensures the uniqueness.

Lemma 5.4. *$T(x;x)$ is strictly decreasing in $(0,D)$.*

Proof.

$$\begin{aligned}
9T(x;x) &= (1-F(x))[K^2 + 2K(2D-\Theta(x)) + (2D-\Theta(x))^2 - K^2] \\
&\quad + F(x)\left[K^2 + 2KD + D^2 - K^2 - 2K\left(\frac{3x+\Theta(x)}{2} - D\right) - \left(\frac{3x+\Theta(x)}{2} - D\right)^2\right] \\
&= (1-F(x))[2K(2D-\Theta(x)) + (2D-\Theta(x))^2] \\
&\quad + F(x)\left[2KD + D^2 - 2K\left(\frac{3x+\Theta(x)}{2} - D\right) - \left(\frac{3x+\Theta(x)}{2} - D\right)^2\right] \\
&= 2K(2D-\Theta(x)) + (1-F(x))(2D-\Theta(x))^2 \\
&\quad + F(x)\left[D^2 + 2K\Theta(x) - 2KD - 2K\left(\frac{3x+\Theta(x)}{2} - D\right) - \left(\frac{3x+\Theta(x)}{2} - D\right)^2\right] \\
&= 2KD + D^2 - F(x)\left[2K\left(\frac{3x+\Theta(x)}{2} - D\right) + \left(\frac{3x+\Theta(x)}{2} - D\right)^2\right] \\
&\quad + 2K(D-\Theta(x))(1-F(x)) + (1-F(x))[2D(D-\Theta(x)) + (D-\Theta(x))^2]
\end{aligned}$$

Now it can be easily seen that $\frac{d}{dx}9T(x) < 0$. This completes the proof. $\square$

Like the case of complete information, the theorem below provides the conditions of pooling and separating equilibria.

Theorem 5.5. *Following hold*

- *If* $M \leq T(D; D)$ *then all the firms will invest in research*
- *If* $M \geq T(0; 0)$ *then no firm will invest in research*
- *Finally, when* $T(D; D) < M < T(0; 0)$*, there exists a unique* δ *such that a firm will invest in research iff its type is less than or equal to* δ *when* δ *can be obtained by solving the equality* $T(\delta; \delta) = M$*.* [7]

The uniqueness of δ given M in the third result is straight from the above lemma.

Since, in the second stage firms are informed about the R&D decision of the rival, this information acts as a signal. So, it is important now to check the incentive compatibility. We claim above that a firm will invest in R&D iff the type of the firm is less than or equal to δ. Suppose firm A follows this strategy and believes firm B to be also following the same strategy. Firm B knows firms A's strategy and belief.

Remark. Suppose firm B's type is greater than δ but it decides to invest in R&D. Here from the second stage onwards firm A believes that the type of the firm B is less than δ. So, firm A will produce accordingly.

So the expected profit of firm B is

$$(1 - F(\delta))\Pi(2D - \Theta(\delta)) + F(\delta)\Pi(D) - M$$

However, if it had not invested, then its expected profit would have been

$$(1 - F(\delta))\Pi(0) + F(\delta)\Pi\left(\frac{3d_B + \Theta(\delta)}{2} - D\right)$$

From the definition of δ and since $T(x; \delta)$ is strictly decreasing in x, we know that for

[7]Note that the value of δ depends on the value of M.

all $d_B > \delta$ the following holds:

$$\left[(1-F(\delta))\Pi(0)+F(\delta)\Pi\left(\frac{3d_B+\Theta\left(\delta\right)}{2}-D\right)\right] > [(1-F(\delta))\Pi(2D-\Theta\left(\delta\right))+F(\delta)\Pi(D)-M]$$

So, if firm B's type is greater than δ, then given firm A's strategy and belief, it will never invest in research.

Remark. Suppose firm B's type is less than or equal to δ but it decides not to invest in R&D. Here from the second stage onwards firm A believes that the type of the firm B is greater than δ. So, firm A will produce accordingly.

So the expected profit of firm B is

$$(1-F(\delta))\Pi(0)+F(\delta)\Pi\left(\frac{3d_B+\Theta\left(\delta\right)}{2}-D\right)$$

However, if it had invested then its expected profit would have been

$$(1-F(\delta))\Pi(2D-\Theta\left(\delta\right))+F(\delta)\Pi(D)-M$$

Again from the definition of δ and since $T(x;\delta)$ is strictly decreasing in x, we know that for all $d_B \leq \delta$ the following holds:

$$[(1-F(\delta))\Pi(2D-\Theta\left(\delta\right))+F(\delta)\Pi(D)-M] \geq \left[(1-F(\delta))\Pi(0)+F(\delta)\Pi\left(\frac{3d_B+\Theta\left(\delta\right)}{2}-D\right)\right]$$

So, if firm B's type is less than or equal to δ then, given firm A's strategy and belief, it will always invest in research.

By optimal strategy under incomplete information we mean that the firm will invest in R&D if and only if the type is less than or equal to δ and believes that the rival is following the same strategy. The above two remarks show that given that the rival is following the optimal strategy mentioned above, it is always optimal for a firm to follow the same strategy. So, both the firms following this strategy is a perfect Bayesian Nash equilibrium.

Below we illustrate our findings with an example.

Example 5.1. Let us assume $a = 10$, $c = 2$, $D = 1$ and $M = 2$. Also assume d_i's are distributed uniformly. So, $K = 8$, $f(x) = 1$, $F(x) = x$, $\Theta(x) = \frac{1+x}{2}$. We have $\Pi(0) = \frac{64}{9}$, $\Pi(D) = 9$, $\Pi(2d_i - D) = \frac{\left(7+\frac{7d_i+1}{4}\right)^2}{9}$ and $\Pi(2D - d_i) = \frac{\left(10-\frac{1+d_i}{2}\right)^2}{9}$. Firm i is indifferent between investing and not investing in research iff

$$(1 - d_i)\left[\left(10 - \frac{1 + d_i}{2}\right)^2 - 64\right] + d_i\left[81 - \left(7 + \frac{7d_i + 1}{4}\right)^2\right] = 18$$

holds. Therefore, $\delta \approx 0.5107$. If research cost is more than 2.917 then no firm will invest in research. On the other hand if there is no research cost then both the firms will always invest in research.

6 Comparison of Threshold Values

To compare the results under incomplete information to complete information, we basically need to compare the threshold values under these two situations. It is important to note that in case of complete information the threshold value depends on the type of the rival firm, whereas in case of incomplete information it does not. So to compare we must first fix the type of the rival firm.

Lemma 6.1. *If it is optimal for a firm to invest in research in case of incomplete information, then she may not invest in research in case of complete information.*

Proof. We show this by giving an example. Suppose d_is are distributed with the distribution function d_i^2 over the interval $[0, 1]$, i.e. $D = 1$. Let $a = 10$ and $c = 2$, so $K = 8$. Let $M = 2.3$, so $\delta \approx 0.4238$. Assume $d_B = 0.9$ and $d_A = 0.41$. Clearly, firm A will invest in research in case of incomplete information. However in case of complete information irrespective of whether the other firm is investing in research or not firm A will never invest in research. □

Lemma 6.2. *If it is optimal for a firm not to invest in research in case of incomplete information, then she may invest in research in case of complete information.*

Proof. We show this by giving an example. Suppose d_is are distributed with the distribution function d_i^2 over the interval $[0, 1]$, i.e. $D = 1$. Let $a = 10$ and $c = 2$, so $K = 8$. Let $M = 2.43$, so $\delta \approx 0.3213$. Assume $d_B = \Theta(\delta)$ and $d_A = 0.33$. Clearly, firm A will not invest in research in case of incomplete information. However in case of complete information irrespective of whether the other firm is investing in research or not firm A will always invest in research. $\square$

The above two lemmas show that whether more information leads to greater probability of research is ambiguous.

7 Conclusion

This paper considers a two stage game where two firms have to decide whether to invest in R&D or not in the first stage and compete in a Cournot duopoly market in the second stage. If a firm invests in R&D, it experiences lower marginal cost. Even if a firm does not invest in R&D, it can still experience some reduction in its marginal cost due to spillover from the R&D of its rival. The spillover parameter of a firm decides how much spillover benefits it can enjoy from its rival's R&D. However, if both the firms invest in R&D then there is no additional benefit due to such spillover of R&D knowledge. In presence of the type of involuntary and automatic spillover of R&D outputs as considered here, every firm gets to learn whether its rival has performed R&D when the concerned firm does not itself conduct R&D. When the firms are aware of each other's spillover parameters, we are in a complete information framework. However, if no firm can observe the spillover parameter of its rival, we are in the world of incomplete information. Here the spillover parameters constitute types and we consider general distribution of types.

Our results show that whether under complete information the firms will invest more in R&D as compared to the situation of incomplete information, cannot be stated unambiguously. The parametric values for which spillovers encourage R&D investments support De Bondt's analysis and our result is thus a generalisation of the incentive creating effects of spillovers in an incomplete information framework.

Here we have considered success to be a definite outcome of R&D. However, there might be associated uncertainties that might be incorporated in the framework of the model. Further research can be done in this direction to identify the conditions for higher R&D incentives for firms in presence of spillover as well as uncertainties in R&D under various information structures.

References

[1] Baker, S., and C. Mezzetti (2005), "Disclosure as a Strategy in the Patent Race", *The Journal of Law and Economics* , 48(1), 173-194.

[2] Baye, M. R., and H. C. Hoppe (2003), "The strategic equivalence of rent-seeking, innovation, and patent-race games", *Games and economic behavior* , 44(2), 217-226.

[3] Conti, C. (2013), "Asymmetric information in a duopoly with spillovers: new findings on the effects of RJVs" (No. 2013-04), http://webmeets.com/files/papers/EARIE/2014/186/Asymmetric

[4] d'Aspremont, C., and A. Jacquemin (1988), "Cooperative and noncooperative R&D in duopoly with spillovers", *The American Economic Review*, 78(5), 1133-1137.

[5] De Bondt, R. (1997), "Spillovers and innovative activities", *International Journal of Industrial Organization*, 15(1), 1-28.

[6] Frick, A., H.C. Hoppe-Wewetzer and G. Katsenos (2016), "R&D and market entry timing with incomplete information", https://editorialexpress.com/cgi-bin/conference/download.cgi?db_name=EEAESEM2016&paper_id=838

[7] Griliches, Z. (1992)," The Search for R&D Spillovers", *The Scandinavian Journal of Economics*, 94, 29-47.

[8] Harhoff, D. (1991), "R&D incentives and spillovers in a two-industry model", (No. 91-06), ZEW Discussion Papers.

[9] Kamien, M. I., E. Muller, and I. Zang (1992), "Research joint ventures and R&D cartels", *The American Economic Review*, 1293-1306.

[10] Katz, M. L. (1986), "An analysis of cooperative research and development", *The RAND Journal of Economics*, 527-543.

[11] Matsumura, T., N. Matsushima and S. Cato (2013), "Competitiveness and R&D competition revisited", *Economic Modelling*, 31, 541-547.

[12] Mookherjee, D., and D. Ray (1991), "On the competitive pressure created by the diffusion of innovations", *Journal of Economic Theory*, 54(1), 124-147.

[13] Reinganum, J.F. (1981), "Market Structure and the Diffusion of New Technology", *The Bell Journal of Economics*, 12(2), 618-624.

[14] Shapiro, C. (1985), "Patent licensing and R&D rivalry", *The American Economic Review*, 75(2), 25-30.

[15] Shibata, T. (2014), "Market structure and R&D investment spillovers", *Economic Modelling* , 43, 321-329.

[16] Suzumura, K. (1992), "Cooperative and Noncooperative R&D in an Oligopoly with Spillovers", *The American Economic Review*, 1307-1320.