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Abstract: It is commonly believed that spillover reduces R&D incentives of a firm. This happen because of the non-appropriability problem. However, some empirical literature shows the possibility of enhanced R&D incentives under spillovers. While this is explained in the literature under incomplete information, we show that this may hold even under complete information. We show in particular that in a duopoly there are situations when with no spillovers only one firm invests in R&D, but under spillovers both the firms invest. This occurs when there is complementarity in research and the spillover is below a critical level.

Keywords: R&D spillovers, non-appropriability problem, complete information, R&D incentives.

JEL Classifications: D43, L13, O31.

1. INTRODUCTION

Spillovers in research and development (R&D) is a common phenomenon. It implies leakages, voluntary or involuntary, of R&D results of an innovator to its rival. Hence in the presence of R&D spillovers the innovator cannot appropriate the full benefit of its innovation. This reduces incentives for R&D investment. The existing literature clearly reveals this under-investment both theoretically and empirically. Arrow (1962) observed that underinvestment in R&D is likely in presence of spillovers. Similar view has been opined by Spence (1984). That a firm can benefit from R&D of its rivals is also evident in Jaffe (1986) which provides empirical evidence of the presence of spillovers. The whole literature on RJV has based its argument on this belief.[1]

However, empirically it is observed that spillovers may not always discourage investments in R&D. For instance, in an empirical study, Levin (1988) has shown that contrary to Spence's prediction, in industries like computers, communications equipment, electronic components and aircraft, spillovers have not resulted in a reduction of R&D investments[2]. One plausible explanation offered for this observed departure of the empirical results from the theoretical prediction is that in electronics based industries, the technical advances are more of "cumulative" rather than "discrete" nature, so that innovations act like "building blocks" or foundations for innovation in the next period. Here spillover of rivals' R&D raises the marginal product of R&D of individual firms and thus the R&D investment goes up as a whole.

De Bondt (1997) finds a different reason for spillovers encouraging R&D investment by firms. Accordingly, the spillover possibilities are likely to encourage R&D as an individual firm's R&D efforts create incentives for other firms to go for similar ventures, and therefore all of them may be able to produce at lower costs resulting in lower prices and hence higher demand.

A recent work by Bakhtiari and Breunig (2018) involves an empirical study that examines the effect of spillovers on firm level R&D investment in Australia. The paper recognizes both positive and negative effects of spillovers and finds that generally negative effects

[1] For instance, see d'Aspremont and Jacquemin (1988), Suzumura (1992), Kamien et al. (1992) and Ghosh and Ghosh (2014).

[2] A comprehensive analysis on the relation between R&D investment and R&D appropriability can be found in Levin et al. (1987).

dominate positive effects, but there are cases when the spillovers encourage firm level R&D investment. This is observed particularly when the firms are located within a geographical distance and engaged in complementary research.

In a more recent work, Chatterjee, Chattopadhyay and Kabiraj (2018) have shown that in an incomplete information framework there are situations when the R&D investment of a firm can be larger in the presence of spillovers compared to the case of no spillovers. This is the case when the innovators have private information about their respective absorptive capacities to acquire, fully or partially, the rival's innovation. Given that the rival's spillover parameter is unknown to the concerned firm, if its absorptive capacity is not large enough, it may invest more in R&D. Then it remains a question of whether the similar result will follow under complete information. This paper seeks to portray situations when even under complete information R&D incentives under spillovers can be larger than that under no spillover situation.

In the present paper we consider the scenario of d'Aspremont and Jacquemin (1988) and their followers, but assume that the R&D investment associated with an innovation is exogenously specified. In particular, we assume that if a firm invests an amount $R > 0$, it reduces its unit cost of production by an amount Δ, and if its rival also invests R, the firm concerned enjoys an additional cost reduction by an amount $\beta\Delta$ $(0 \leq \beta \leq 1)$ due to spillovers. Thus when both firms invest R in R&D, each firm benefits from the other's investment; as a result, each firm enjoys, effectively, a cost reduction of $(1 + \beta)\Delta$. So this acts like the synergy or network effect.[3]

This synergy effect can be well understood in terms of a real life example. Suppose there are two companies each producing computers. If both of them undertake cost reducing R&D, due to which one of them is able to reduce the cost of producing motherboard and the other succeeds in reducing the cost of producing processors, then both will benefit from cross spillover effects. This is because the R&D results are complementary in nature and this reduces costs along two different channels.

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[3] This effect is actually absent in Chatterjee et al. (2018), as a result in their paper under complete information spillovers unambiguously reduce R&D incentives of a firm.

From the above discussion it follows that the presence of spillovers may enhance R&D investment. Hence the purpose of the present paper is to show that, given the spillovers of R&D, even under complete information framework spillovers may enhance R&D incentives of a firm compared to the no spillover case. We show in particular that when only one firm invests in R&D under no spillover situation, then under spillover effect both the firms will invest in R&D if the spillover is below a critical level. However, if under no spillover case, no firm invests in equilibrium, then under spillover none will invest in R&D.

The organisation of the paper is as follows. In the following section 2 we provide the model and results of the paper. Section 3 concludes the paper.

2. MODEL AND RESULTS

Consider two firms, call firm 1 and firm 2. They play a two-stage game. In the first stage, they simultaneously and non-cooperatively decide whether they will invest in R&D or not, and then in the second stage, they play a Cournot game. Their initial unit cost of production is $c > 0$. We now assume that if a firm invests an amount $R > 0$ in R&D, it comes up with an innovation that reduces its unit cost of production by an amount D with certainty, and $0 < D < c$. The market demand for the product they produce is linear and in inverse form given by $P = \max\ \{0, a - Q\}$ where $a > 0$ is the demand shift parameter, $Q\ (= q_1 + q_2)$ is the aggregate output produced in the market at price P, and q_i is the output produced by firm i. We assume that the innovation is non-drastic so that the market structure always remains to be duopoly, i.e. $a - c > D$.

When a firm innovates, let d be the extent of spillover that goes to the firm, hence $0 \leq d \leq D$; $d = 0$ implies no spillover and $d = D$ implies cent percent spillover. Therefore, if only one firm innovates, its unit cost of production becomes $c - D$, but its rival's unit cost of production becomes $c - d$. When both the firms innovate, each firm's unit cost becomes $c - D - d$.[4]

[4] Following the works of d'Aspremont and Jacquemin (1988), Kamien et.al. (1992) and others, the effective cost reduction of firm i through spillover is $\varepsilon_i = \phi(R_i) + \beta\phi(R_j)$, where $\phi(R_i)$ is the amount of cost reduction if R_i is invested by firm i; $\phi(0) = 0$ and $\beta \leq 1$. In our case, $R_i = R_j = R$, $\phi(R) = D$ and $\beta D = d$. Alternatively, we can assume that production of the final good requires one unit of each of the two inputs X and Y and initial unit costs of X and Y are c_X and c_Y respectively so that its initial unit cost of production is $c = c_X + c_Y$. Now assume that firm 1 can reduce unit cost of X by D amount if it invests R in R&D. similarly, firm 2 can reduce its unit cost of Y by the same amount by investing R. By this, there is spillover of knowledge, d, from one firm to the other; $0 \leq d \leq D$.

Consider the following notations: $A = a - c$, $q(x) = \frac{A+x}{3}$, and $\Pi(x) = [q(x)]^2$ where $q(x)$ and $\Pi(x)$ are, respectively, quantity and profit of a firm. Clearly, the $\Pi(x)$ function is strictly increasing and strictly convex in x. In the first stage, each firm has two strategies -- either invest in R&D (denoted by Y) or do not invest (N). Therefore, in the absence of spillovers (WS), the payoffs of the firms for different combinations of Y and N are given by the payoff matrix in Table 1.

Table 1: Payoff matrix under complete information without spillovers (WS)

		Firm 2	
		Y	N
Firm 1	Y	$\Pi(D) - R, \Pi(D) - R$	$\Pi(2D) - R, \Pi(-D)$
	N	$\Pi(-D), \Pi(2D) - R$	$\Pi(0), \Pi(0)$

Similarly, in the presence of spillovers (SS), the payoffs of the firms are given by the payoff matrix in Table 2.

Table 2: Payoff matrix under complete information with spillovers (SS)

		Firm 2	
		Y	N
Firm 1	Y	$\Pi(D + d) - R, \Pi(D + d) - R$	$\Pi(2D - d) - R, \Pi(2d - D)$
	N	$\Pi(2d - D), \Pi(2D - d) - R$	$\Pi(0), \Pi(0)$

Let us now define non-strategic R&D incentive (NS) of a firm to be the difference between its payoffs from doing and not doing R&D when the rival does not do any R&D. Similarly, strategic R&D incentive (S) of a firm is the difference between its payoffs from doing and not doing R&D when the rival does R&D. Hence,

$$NS(WS) = \Pi(2D) - \Pi(0) - R, \quad S(WS) = \Pi(D) - \Pi(-D) - R$$

$$NS(SS) = \Pi(2D - d) - \Pi(0) - R, \quad S(SS) = \Pi(D + d) - \Pi(2d - D) - R$$

Then,

$$S(WS) - NS(WS) = (\Pi(\,D) - \Pi(\,-D)) - (\Pi(\,2D) - \Pi(0))$$

Since the $\Pi(\cdot)$ function is strictly convex and increasing, we must have

$$S(WS) - NS(WS) < 0 \tag{1}$$

i.e., under no spillover, non-strategic R&D incentive is strictly larger than strategic R&D incentive.

To compare the strategic and non-strategic incentives under spillover, consider

$$S(SS) - NS(SS) = \Pi(D + d) - \Pi(2d - D) - \Pi(2D - d) + \Pi(0)$$

It is easy to see that $[S(SS) - NS(SS)]$ is strictly increasing function of d with $[S(SS) - NS(SS)]_{d=0} < 0$, $[S(SS) - NS(SS)]_{d=D} > 0$, and $[S(SS) - NS(SS)]_{d=\frac{D}{2}} = 0$. Therefore,

$$S(SS) - NS(SS) \lesseqgtr 0 \Leftrightarrow d \lesseqgtr \frac{D}{2} \tag{2}$$

This states that with spillovers, strategic incentives of R&D are larger than the non-strategic incentives for all $d \in (\frac{D}{2}, D]$.

Next we discuss the effect of spillovers on non-strategic and strategic incentives of R&D. We have:

$$NS(SS) - NS(WS) = \Pi(2D - d) - \Pi(2D) < 0 \;\; \forall\, d > 0 \tag{3}$$

This means, spillovers unambiguously reduce non-strategic R&D incentive.

Now,

$$S(SS) - S(WS) = \Pi(D + d) - \Pi(2d - D) - \Pi(D) + \Pi(-D)$$

Then it can be shown that

$$9[S(SS) - S(WS)] = (6D - 2A - 3d)d$$

Therefore,

$$S(SS) - S(WS) > 0 \text{ for } 0 < d < \frac{2}{3}(3D - A) \equiv d^* \quad (4)$$

Clearly, d^* is interior for $A < 3D < 2A$, and $d^* = D$ for $3D \geq 2A$.

From (3) and (4) we can write the following proposition.

Proposition 1: While spillovers always reduce non-strategic incentive of R&D, it will increase strategic incentive if $d \in (0, d^*)$ and $A < 3D$.

Now consider Nash equilibrium (NE) of each R&D game portrayed in Table 1 and Table 2. We have the following results:

Proposition 2:

(a) When there are no spillovers,
  - (i) (Y, Y) is NE if $S(WS) > 0$,
  - (ii) (Y, N) and (N, Y) are Nash equilibria if $S(WS) < 0 < NS(WS)$, and
  - (iii) (N, N) is the NE if $NS(WS) < 0$

(b) When there are spillovers of R&D,
  - (i) (Y, Y) is NE if $S(SS) > 0$,
  - (ii) (Y, N) and (N, Y) are Nash equilibria if $S(SS) < 0 < NS(SS)$, and
  - (iii) (N, N) is NE if $NS(SS) < 0$.

The above conditions can be stated in terms of R&D investment explicitly. In general if R&D investment, R, is small, both firms will invest in R&D; if it is high, no firm will invest in R&D; and if it is in the intermediate range, only one firm will invest in R&D.

Now, we examine whether in equilibrium R&D incentives are larger in the presence of spillovers compared to no spillover case. In our scenario, spillovers will enhance R&D incentive if in equilibrium (i) no firm invests in R&D under no spillover case but at least one firm invests under spillovers, or (ii) only one firm invests under no spillover case, but both firms invest under spillovers.

First, suppose that (N, N) is the NE when there is no spillover of R&D and (Y, N) (or (N, Y)) is the NE when there are spillovers. This requires to satisfy the following two conditions simultaneously, that is,

(I) $NS(WS) < 0$ and $S(SS) < 0 < NS(SS)$

But given that by (3), $NS(SS) < NS(WS)$, (I) cannot be satisfied. Hence, if (N, N) is the NE when there is no spillover, then (Y, N) or (N, Y) cannot be a NE when there are spillovers.

Now consider whether (N, N) is the NE when there is no spillover but (Y, Y) is the NE when there are spillovers. These two together require to satisfy the following inequality,

(II) $NS(WS) < 0 < S(SS)$.

We have,

$$NS(WS) - S(SS) = \Pi(2D) - \Pi(0) - \Pi(D + d) + \Pi(2d - D)$$

Then it can be shown that,

$$9[NS(WS) - S(SS)] = 4D(D - d) + 2d(A - D) + 3d^2$$

Therefore, given $d \leq D < A$, we have,

$$NS(WS) - S(SS) > 0 \;\; \forall d \in [0, D] \quad (5)$$

Hence (II) will never be satisfied. This means, (N, N) with no spillover and (Y, Y) with spillover cannot be simultaneously NE of the game.

Finally, we examine whether simultaneously (Y, N) (or (N, Y)) is the NE in the absence of spillovers and (Y, Y) is the NE in the presence of spillovers. For this to hold we need to satisfy simultaneously the following two conditions:

(III) $S(WS) < 0 < NS(WS)$ and $S(SS) > 0$

Note that by (1), $S(WS) < NS(WS)$, and by (4), $S(SS) > S(WS)$ for $0 < d < d^*$. Finally, we have shown that $NS(WS) > S(SS)$ (see (5)). Therefore,

$$\exists\, (d, R) \text{ such that } S(WS) < 0 < S(SS) < NS(WS) \quad (6)$$

This means, (Y, N) or (N, Y) under no spillover and (Y, Y) under spillover will be simultaneously Nash equilibria if spillover parameter is below a critical level and R is in the intermediate range. Under this situation spillovers increase incentives of R&D.

Proposition 3: When R&D investment is in the intermediate range and spillovers are below a critical level, R&D incentives of firms are larger under presence of spillovers compared to no spillover case.

Our result clearly shows that even under complete information spillovers may enhance R&D incentives. This will certainly be the case when R&D investment is neither too small nor too large and spillover rate is low. Under this situation strategic incentive of firms are larger and each firm through R&D attempts to benefit from spillovers of other firm's knowledge.

3. CONCLUSION

It is very common to believe that in a complete information structure the presence of spillovers in R&D will reduce R&D investment of a firm. Presence of spillovers implies that some R&D knowledge of an innovator leaks out to its rival competitors, hence the innovator cannot get the full benefit of its R&D investment. This induces the firm to under-invest in R&D. In the present paper we argue that when all the competing firms invest, each firm gets the benefit from other firms' investment and the total ex ante gain can be large enough to induce the firm invest in R&D. Actually, in such a situation spillovers act as network externalities. As we have shown in the paper, this occurs when R&D investment is neither too large nor too small, and the size of the innovation is relatively large so that even a small degree of spillover enhances profits of the firm. In our paper we have shown in particular that in a duopoly when only one firm innovates in equilibrium if there is no spillover, then in the presence of spillovers both firms will invest in research. However, if no firm invest in research when there is no spillover, we find that no firm will have any incentive to invest in research when there are spillovers. Thus our paper draws attention to the case that R&D incentive may go up with presence of spillover even under complete information.

References

Arrow, K.J. (1962), "Economic welfare and the allocation of resources for invention", in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, 609-625.

Bakhtiari, S. and R. Breunig (2018), "The role of spillovers in research and development expenditure in Australian industries", *Economics of Innovation and New Technology*, 27(1), 14-38.

Chatterjee, R., S. Chattopadhyay and T. Kabiraj (2018), "Spillovers and R&D incentive under incomplete information", *Studies in Microeconomics* (forthcoming)

d'Aspremont, C., and A. Jacquemin (1988), "Cooperative and non-cooperative R&D in duopoly with spillovers", *American Economic Review*, 78, 1133-1137.

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

Ghosh S. and S. Ghosh (2014), "Are cooperative R&D agreements good for the society?", *Journal of Business & Economics Research*, 12, 313-322.

Jaffe, A.B. (1986), "Technological opportunity and spillovers of R&D: evidence from firms' patents, profits and market value", *American Economic Review*, 76, 984-1001.

Kamien, M.I., E. Muller, and I. Zang (1992), "Research joint ventures and R&D cartels", *American Economic Review*, 82, 1293-1306.

Levin, R.C., A.K. Klevorick, R. Nelson and S. Winter (1987), "Appropriating the returns from industrial R&D", *Brookings Economic Papers on Economic Activity*, 18, 783-832.

Levin, R.C. (1988), "Appropriability, R&D spending, and technological performance", *American Economic Review*, 78, 424-428.

Spence, M. (1984), "Cost reduction, competition and industry performance", *Econometrica*, 52, 101-121.

Suzumura, K. (1992), "Cooperative and non-cooperative R&D in an oligopoly with spillovers", *American Economic Review*, 82, 1307-1320.