The effects of licensing on firms incentive to cooperate and invest in innovation

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Abstract
In this paper, we propose a theoretical model where two firms invest in a stochastic cost-reducing innovation. We evaluate the private incentive to cooperate comparing three different scenarios (R&D Cartelization, RJV Cartelization, and R&D Competition), in terms of expected profits, R&D expenditure, and industry probability of innovation. In this framework, we introduce licensing contracts as additional instruments that firms can use to commercially exploit innovation, and analyze their impact on market equilibria and efficiency of private R&D decisions. We show that the introduction of licensing increases R&D return appropriability, stimulates competition and investment, increasing the cases where competition in R&D is welfare-enhancing; i.e., the introduction of licensing reduces the need for public intervention to boost cooperation.

Keywords: innovation; licensing; R&D cooperation; R&D expenditure.

JEL Code: D45; 032; L13; L50

1. Introduction

The importance of R&D investment as one of the main factor in firms' strategy, and in general for the economic growth, is unquestionable. However, R&D has the characteristics of a public good: it is both non-rival and not completely excludible, generating positive externality by spillovers. This implies that the chosen level of R&D activities may be too low, with respect to the social optimum (Arrow, 1962). For this reason, governments and supranational organizations tend to stimulate innovation through subsidies and other forms of public incentives; for example, in recent years, the European Union has focused on incentive systems to boost R&D investment, such as the so-called *'Barcelona and Lisbon objectives and the Agenda 2020'*. The major objective is to increase the average gross expenditure on research and development (GERD) to 3.0%, of which two-thirds should be funded by the private sector. Some European countries support this policy by national incentives as well.[1]

The idea supporting public intervention is that it boosts firms in activities and investments they would not have undertook, leading to new processes or products and improving their performances. Unfortunately, these mechanisms may not work: all the firms can (and presumably do) apply for public incentives, even the ones that would have invested in R&D without the incentives. In this case, public incentives crowd-out the private investment and there is no additionality in R&D. In other words, when there is public support to R&D, firms might simply substitute public for private investment. Thus, economic literature has investigated some alternative strategies to stimulate investment. One is the R&D cooperation; indeed, recent studies highlight a positive impact of R&D cooperation on additionality.[2] However, R&D Cooperation does not emerge in all the cases where it represents an instrument to achieve the social optimum,and it should also be subsidized. Spillovers, market competition, public incentives, etc.,[3] affect firms' incentive to cooperate; in this framework, economic literature has neglected the role of licensing.[4] In this paper we fill this gap, considering licensing as an additional instrument that firms can use to commercially exploit the innovation. We show that the introduction of licensing reduces the firms' incentives to cooperate; nevertheless, by increasing return appropriability, licensing stimulate R&D investment, reducing the cases where public intervention is needed. In particular, we concentrate our analysis on industry R&D expenditure and probability to achieve innovation.

We contribute to the theoretical literature by introducing several elements of novelty. First, differently from most of the literature, which concentrate on firms' profits and social welfare,[5] we analyze the R&D expenditure and the probability of achieving the innovation, since, differently from social welfare, these variables are straightforwardly measurable, and there exists a huge empirical literature that uses them to estimate the innovative performance. Second, despite the increasing literature on the contracts agreements between firms, analysis on the impact of licensing on the R&D investment decisions are still scant, and, to the best of our knowledge, this is the first contribution to study the effect of licensing on R&D cooperation. Finally, we suggest policy indications of public intervention for R&D cooperation, both with and with-

[1] In recent years, in Europe programs such as ESPRIT, IST, and EUREKA! were implemented.

[2] See Czarnitzki et al. (2007), Pippel (2014), and Pippel and Seefeld (2016).

[3] For a recent analysis on the determinants of R&D cooperation see Cantabene and Grassi (2019).

[4] Licensing is a contractual agreement between a firm (the licensor) who makes a legally protected asset available to others (the licensees) in return for royalties, license fees, and other forms of compensations.

[5] For recent contribution see Cabon-Dhersin and Gibert (2019).

out licensing; our analysis shows that, contrary to the seminal literature on R&D and spillovers,[6] forming an RJV may not be the social optimum. Consequently, subsidizing any RJV is not always efficient. On the contrary, boosting licensing contract increases R&D appropriability and private investment even though firms do not cooperate in R&D. Thus, the cases where non-cooperation is the social optimum increase and the need for public intervention is reduced.

The paper is organized as follows: Section 2 locates the paper with respect to the literature; Section 3 presents the model; Section 4 studies the equilibria of the game; Section 5 extends the analysis to the case where the innovative firm licenses its innovation; Sections 6 concludes. Proofs are in the Appendix.

2. Related literature

The empirical literature has analyzed in deep the effects of public incentives (e.g., R&D tax credits and direct subsidies) on firms' investment decisions, to understand if the crowding-out effect exists.[7] The results are mixed, depending on the tested hypothesis, the sample, the kind of incentive, etc. In recent years, economic analysis has focused on the cooperation between firms, suggesting that boosting R&D cooperation may be an efficient instrument to stimulate innovation. Indeed, firms cooperation leads to economic growth, and facilitating the information flows (spillovers) between the economic agents, improves their performance in terms of innovation (Lopez, 2008). Some empirical evidence highlights the positive impact of R&D Cooperation on additionality.[8]

The theoretical literature on R&D cooperation and its impact on investments date back to D'Aspremont and Jacquemin (1988), whose model was extended by Kamien et al. (1992). The latter evaluates the private incentive to cooperate comparing three different scenarios (R&D Cartelization; RJV Cartelization; R&D Competition). Ranking the equilibria, they found that, for spillovers high enough, cooperating in R&D firms increase investment, with positive effects on profits and social welfare. In general, scholars focus on the role of subsidies on R&D activities,[9] and shows that, above a certain spillover threshold, R&D cooperation increases investments, profits, and social welfare.[10]

The literature on licensing is huge. It dates back at least to Katz and Shapiro (1985), who shows how the possibility of licensing may raise prices and decrease the returns on innovation. This branch of the literature concentrates on the comparison between ad valorem and per-unit royalties, under different hypothesis (e.g., quantity vs price competition, homogeneous vs. differentiated goods, etc.).[11] More sporadically, some authors analyze the effect of licensing on social welfare, with non-univocal results;[12] other scholars analyze the impact of licensing on the firm's incentive to innovate,

[6]See, for example, Kamien et al. (1992).

[7]Surveys of the literature in Zúñiga-Vicente et al. (2014), Castellacci and Lie (2015), Becker (2015). A resume of some results in Cantabene and Grassi (2019).

[8]See Czarnitzki et al (2007), Pippel (2014), and Pippel and Seefeld (2016).

[9]On this topic, see the seminal contributions by Hinloopen (1997, 2000).

[10]Other contributes include Choi (1993), Leahy and Neary (1997) and Goyal and Moraga-Gonzalez (2001); more recently, Cabon-Dhersin and Gibert (2019).

[11]See, inter alia, Kamien and Tauman (1986), Gallini and Wright (1990), San Martín and Saracho (2010 and 2015), Duchene et al. (2015), Colombo and Filippini (2015 and 2016).

[12]See, inter alia, Fauli-Oller and Sandonis (2002), Chowdhury (2005), Sen and Tauman (2007), Bertran and Turner (2017).

obtaining, in general, that when a firm can license its innovation, the R&D effort is higher.[13] Furthermore, increasing R&D has positive effects on welfare, when licensing is allowed,[14] with some differences according to the type of licensing contract (e.g., fixed fee, or ad valorem royalties).[15]

To the best of our knowledge, there is a lack of contributions on the effect of licensing on R&D cooperation, and its impact on the investment decisions of the firms. However, our results are comparable with the findings reported in Colombo (2019), that analyzes the impact of licensing in an R&D decision model. He focuses on the equilibrium amount of deterministic cost-reducing innovation under several licensing mechanisms, showing that in the case of ad valorem licensing innovation under licensing is always higher than innovation under no licensing. We confirm this result in the case of stochastic cost-reducing innovation with the optimal two-part license: licensing, granting higher profit, boosts firm to invest more with respect to the no-cooperative scenario. In addition, we extend the analysis introducing cooperation. We show that, even if the introduction of licensing reduces the set of parameters where cooperation emerges spontaneously in equilibrium, the non-cooperative scenario is now characterized by higher levels of investment in R&D and probability of innovation, and this reduces the need for public intervention.

3. The model

3.1. *Model setting*

We consider a duopoly where two incumbents ($i = 1, 2$) compete *à* la Cournot, producing and selling a homogenous good x characterized by the standard inverse demand function: $P = 1 - X$ where P is the price and $X = x_1 + x_2$ the total quantity. The production process has constant returns to scale, with symmetric marginal cost equal to $c > 0$. In a pre-entry stage $t = 0$, firms can invest in stochastic cost-reducing R&D activities, either jointly or non-cooperatively. Investing $\rho_i^2/2$, firms obtain with probability $\rho_i \in [0, 1]$ an innovation that reduces the marginal cost from c to c'. For simplicity, we assume $c' = 0$. In the industry there are knowledge spillovers; this means that, if one firm innovates, the other can successfully imitate the new technology, with a probability $\beta \in [0, 1]$.

Following the seminal contribution by Kamien et al. (1992), we consider three alternative scenarios: R&D Competition (case N), R&D Cartelization (case C), and RJV Cartelization (case J). In R&D Competition firms decide independently their own R&D efforts; in R&D Cartelization firms coordinate their R&D activities in independent research lines, so as to maximize the joint profit; in RJV Cartelization firms create a research joint venture and coordinate their R&D efforts in a common research line, so as to maximize the joint profit. In the two cooperative scenarios, firms internalize spillovers ($\beta = 1$) and, in case of success in innovation, they jointly patent the new technology. The timing is the following:

- at $t = 0$, firms decide whether cooperate (C or J) or not (N);
- at $t = 1$, firms decide the level of innovative effort;
- at $t = 2$, Nature defines whether R&D process is successful or not; if only one firm innovates, the other imitates or not with a probability β (spillovers);

[13] See, inter alia, Salant (1984), Gallini and Winter (1985), Mukherjee and Mukherjee (2013), Colombo (2019).
[14] See Colombo and Filippini, 2014.
[15] See San Martin and Saracho, 2010.

- at $t = 3$, firms compete *à* la Cournot.

In the following, we analyze the three different scenarios (C, J and N).

3.2. *R&D Competition (N)*

At $t = 0$, firms can choose to not cooperate, investing in independent research lines, under the risk to be imitated with probability β (case N). Investing $\frac{(\rho_i)^2}{2}$, firm i obtains the symmetric/efficient duopoly profit $\widetilde{D} = \frac{1}{9}$ with probability $\rho_i \rho_j + \rho_i (1 - \rho_j) \beta + \rho_j (1 - \rho_i) \beta$; this occurs either when both firms innovate, or when one innovates and the other imitates (by spillovers). Firm i obtains the symmetric/inefficient duopoly profit $D_0 = \left(\frac{1-c}{3}\right)^2$ with probability $(1 - \rho_j)(1 - \rho_i)$; this occurs when none of them innovates. Finally, when only one firm innovates and no spillovers occur, firms compete in an asymmetric duopoly. With probability $\rho_i (1 - \rho_j)(1 - \beta)$ firm i innovates, while the rival neither innovates nor imitates; in this case, firm i obtains profits equal to $\overline{D} = \left(\frac{1+c}{3}\right)^2$. With probability $\rho_j (1 - \rho_j)(1 - \beta)$, firm j innovates, while firm i neither innovates nor imitates; in this case, firm i obtains profits equal to $\underline{D} = \left(\frac{1-2c}{3}\right)^2$.

Thus, in the case of R&D Competition, firm i's expected profit is:

$$\Pi_i^N = \left(\rho_i^N \rho_j^N + \rho_i^N \left(1 - \rho_j^N\right) \beta + \rho_j^N \left(1 - \rho_i^N\right) \beta\right) \widetilde{D} + \\ + \left(1 - \rho_i^N\right)\left(1 - \rho_j^N\right) D_0 + \rho_j^N \left(1 - \rho_i^N\right)(1 - \beta) \underline{D} + \\ + \rho_i^N \left(1 - \rho_j^N\right)(1 - \beta) \overline{D} - \frac{\left(\rho_i^N\right)^2}{2} \quad (1)$$

where ρ_i^N and ρ_j^N are the probabilities of innovation of the competing firms. Furthermore, we have that:

$\widetilde{D}$ is the per-firm symmetric/efficient duopoly profit;
D_0 is the per-firm symmetric/inefficient duopoly profit;
$\underline{D}$ is the inefficient firm's profit in the case of cost asymmetry;
$\overline{D}$ is the efficient firm's profit in the case of cost asymmetry.

3.3. *Cooperation in R&D*

Alternatively to competition in R&D, at $t = 0$, firms can choose to cooperate, investing either in independent research lines (case C), or in a common line (case J). As standard in the literature, we assume perfect observability and/or full commitment of the coordinated actions in the cooperative scenarios.

3.3.1. R&D Cartelization (C)

R&D Cartelization describes the case where firms choose the individual level of investment that maximizes the joint profits, investing in independent R&D lines. In this case, investing $\frac{\rho_i^2}{2}$ each firm obtains: with probability $1 - (1 - \rho_i)^2$ the symmetric duopoly profit $\widetilde{D}$ associated with $c' = 0$ (success in innovation); with probability $1(-\rho_i^C)^2$ the symmetric duopoly profit D_0 associated with $c > 0$ (fail in innovation).[16] Thus, firm i's expected profit is:

$$\begin{aligned}\Pi_i^C &= \left(1-(1-\rho_i^C)^2\right)\widetilde{D}+(1-\rho_i^C)^2 D_0-\frac{\left(\rho_i^C\right)^2}{2}= \\ &= \frac{\left(1-(1-\rho_i^C)^2\right)}{9}+(1-\rho_i^C)^2\left(\frac{1-c}{3}\right)^2-\frac{\left(\rho_i^C\right)^2}{2}\end{aligned} \tag{2}$$

where ρ_i^C is the probability of innovation chosen by the coordinating firms.

3.3.2. RJV Cartelization (J)

RJV Cartelization describes the case where firms cooperate, creating a research joint venture and sharing the investment costs. Thus, investing $\frac{1}{2}\left(\frac{\rho_i^2}{2}\right)$, each firm obtains: with probability ρ_i the symmetric duopoly profit $\widetilde{D}$ associated with $c' = 0$ (success in innovation), with probability $1 - \rho_i$ the symmetric duopoly profit D_0 associated with $c > 0$ (fail in innovation). Thus, firm i's expected profit is:

$$\begin{aligned}\Pi_i^J &= \rho_i^J(\widetilde{D})+(1-\rho^J)D_0-\frac{1}{2}\cdot\frac{\left(\rho_i^J\right)^2}{2}= \\ &= \frac{\rho_i^J}{9}+(1-\rho^{i}{}^J)\left(\frac{1-c}{3}\right)^2-\frac{\left(\rho_i^J\right)^2}{4}\end{aligned} \tag{3}$$

where ρ_i^J is the probability of innovation fixed by the joint venture.

4. The equilibria of the game

We look at the Subgame Perfect Nash Equilibrium (SPNE). Solving the game by backward induction, we obtain the per-firm expected profits, computed according to the Equations (1), (2) and (3). In Table 1, we report the per-firm expected profits, Π^C, Π^J, and Π^N; while, in Table 2, we report the industry R&D expenditures E, and the industry probabilities of innovation P, computed as the probabilities that at least one firm innovates. The two tables are in the Appendix.

4.1. *Innovation outcomes*

The industry R&D expenditure measures the private effort to innovate; it positively depends on the cost c as a measure of innovation efficiency.[17] It does not depend on the level of spillovers in the cases of cooperation (J and C), since the spillovers are entirely internalized and fixed at $\beta = 1$. On the contrary, when the firms operate non-cooperatively (case N), R&D expenditure is inversely correlated to the level of β, since high values of spillovers causes high risk of imitation and low R&D return appropriability.

[16]Indeed, in this scenario, firms invest in two independent R&D lines. Both obtain the new technology if at least one of them innovates; i.e., innovation occurs with a probability equal to $\rho_i + \rho_j - \rho_i \cdot \rho_j = 1 - (1 - \rho_i)^2$ when we assume $\rho_j = \rho_i$.
[17]In fact, $\Delta c = c_0 - c\prime = c$.

Comparing the values reported in Table 2, we check whether cooperation boosts higher R&D expenditure; i.e. whether cooperation causes an increase in the industry R&D expenditure with respect to the non-cooperative scenario. Thus, we state the following proposition.

Proposition 1. *There exists a set*

$$A_1 \cup A_2 \equiv \left\{ (\beta, c) \subset [0,1] \times [0, 0.5] : \; \beta \leq \frac{34c - 24c^2 + 8c^3}{25c - 24c^2 + 8c^3 + 18} = \beta_0 \right\}$$

such that R&D Competition achieves the highest level of industry R&D expenditure; i.e. $E^N = MAX\left[E^J, E^C, E^N\right]$;

there exists a complementary set

$$B_1 \cup B_2 \equiv \{(\beta, c) \subset [0,1] \times [0, 0.5] : \beta > \beta_0\}$$

such that R&D Cartelization achieves the highest level of industry R&D expenditure; i.e., $E^C = MAX\left[E^J, E^C, E^N\right]$.

Proof. In Appendix. ■

When firms cooperate, R&D Cartelization, characterized by independent research lines, leads to higher R&D expenditures than RJV cartelization, characterized by a joint research line (i.e., $E^C > E^J$). Comparing R&D Cartelization and R&D Competition, we have to consider the role of spillovers, which affect investment decisions. When knowledge spillovers are sufficiently low (i.e., $\beta < \beta_0$) the probability of imitation is low; thus, the investor likely becomes the more efficient firm in an asymmetric duopoly (it innovates and the other does not imitate). In this case, each firm invests more compared to the cooperative case where, at best, it obtains the symmetric efficient duopoly profits. For high values of spillovers (i.e., $\beta \geq \beta_0$) we have the opposite result, since the possibility to be the only efficient firm is reduced.

The target of any R&D activity is to achieve innovation. In a stochastic model any additional effort that increases the probability to get the new product or technology increases the probability to obtain the innovation as well. However, the probability of innovation also strictly depends on the innovative process technology that differs in the proposed scenarios: firms jointly invest in the same research line in the case of R&D Cartelization while they invest (cooperatively or not) in independent research lines in the other two scenarios. In particular, for the same level of R&D effort, the RJV Cartelization is associated with the highest probability of failing in innovation, $1 - P^J = 1 - \rho$, compared to the one associated with the other scenarios, $1 - P^C = 1 - P^N = (1 - \rho)^2$. It follows that, for each value of the parameters, if $\rho^C > \rho^J$ then $P^C >> P^J$. Moreover, comparing cooperation with competition in R&D, since there are independent research lines, the probability of innovation coincides in R&D Cartelization and R&D Competition, when the firms' innovative efforts are the same. It follows that, for spillovers low enough ($\beta \leq \beta_0$) the innovative effort and, consequently, the probability of innovation is higher in the case C. For high spillovers ($\beta > \beta_0$), the reverse occurs. Previous intuition supports the following proposition.

Proposition 2. *There exists a set*

$$A_1 \cup A_2 \equiv \left\{ (\beta, c) \subset [0,1] \times [0, 0.5] : \ \beta \leq \frac{34c - 24c^2 + 8c^3}{25c - 24c^2 + 8c^3 + 18} = \beta_0 \right\}$$

such that R&D Competition achieves the highest level of probability of innovation; i.e. $P^N = MAX\left[P^J, P^C, P^N\right]$;

there exists a complementary set

$$B_1 \cup B_2 \equiv \{(\beta, c) \subset [0,1] \times [0, 0.5] : \beta > \beta_0\}$$

such that R&D Cartelization achieves the highest level of probability of innovation; i.e., $P^C = MAX\left[P^J, P^C, P^N\right]$.

Proof. In Appendix. ■

Figure 1 illustrates Propositions 1 and 2. In Area $A_1 \cup A_2$, in terms of industry R&D expenditure and probability of innovation, R&D Competition dominates any form of cooperation; in Area $B_1 \cup B_2$, R&D Cartelization leads to the highest level of R&D expenditure. Summing up, in Area $A_1 \cup A_2$ where the spillovers are not so high (i.e., $\beta \leq \beta_0$), R&D Competition achieves the highest innovative performance and boosting cooperation is not socially efficient. In Area $B_1 \cup B_2$,where the spillovers are high enough (i.e., $\beta > \beta_0$), R&D Cooperation is welfare-enhancing.

However, R&D Cooperation emerges in equilibrium when it leads to the highest profit. In Table 1 we report the firms' profits in the different scenarios. Their comparison allows stating the following proposition:

Proposition 3. *There exists a set*

$$A_2 \cup B_2 \equiv \left\{(\beta, c) \subset [0,1] \times [0, 0.5] : \Pi^N \geq \Pi^C\right\}$$

such that R&D Competition achieves the highest level of per-firm profits; i.e. $\Pi^N = MAX\left[\Pi^J, \Pi^C, \Pi^N\right]$;

there exists a complementary set

$$A_1 \cup B_1 \equiv \left\{(\beta, c) \subset [0,1] \times [0, 0.5] : \Pi^C \geq \Pi^N\right\}$$

such that R&D Cartelization achieves the highest level of per-firm profits; i.e., $\Pi^C = MAX\left[\Pi^J, \Pi^C, \Pi^N\right]$.

Proof. In Appendix. ■

Figure 1 illustrates Proposition 3. In Area $A_2 \cup B_2$, R&D Competition dominates any form of cooperation; in Area $A_1 \cup B_1$, R&D Cartelization emerges in equilibrium. RJV Cartelization is always dominated.

4.2. *Efficiency in private decisions of cooperation*

Referring to Figure 1, Proposition 3 states that in Area $A_2 \cup B_2$, R&D Competition emerges in equilibrium. However, Propositions 1 and 2 state that in Area $A_1 \cup A_2$, R&D

Competition leads to the best social outcome. Thus, boosting cooperation is necessary only in Area B_2; it spontaneously emerges in Area B_1 where public intervention is a waste of resources. In Area A_2, the market equilibrium leads to the social optimum and, again, no public intervention is required. Finally, in Area A_1, cooperation emerges in equilibrium but competition is welfare enhancing.

Summing up, public intervention is required in Areas A_1 and B_2. However, the target of intervention is different: in Area B_2 cooperation should be subsidized; in Area A_1 competition should be boosted, for example, through public funds for independent R&D investment.

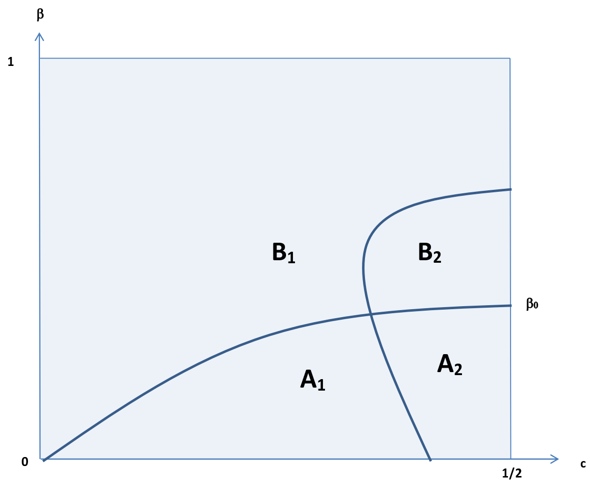

Figure 1. The equilibria of the game.

5. Licensing (L)

In this section, we introduce the possibility of licensing agreements in the non-cooperative scenario (case L).

When only one firm innovates and imitation by spillovers does not occur, the innovator can propose a sole license to the rival. The latter can accept or not the proposal. Thus, firm i's expected profit becomes:

$$\begin{aligned}\Pi_i^L = &\left(\rho_i^L \rho_j^L + \rho_i^L \left(1-\rho_j^L\right)\beta + \rho_j^L \left(1-\rho_i^L\right)\beta\right)\widetilde{D} + \\ &+ \left(1-\rho_i^L\right)\left(1-\rho_j^L\right)D_0 + \rho_j^L \left(1-\rho_i^L\right)(1-\beta)\underline{D}_i^L + \\ &+ \rho_i^L \left(1-\rho_j^L\right)(1-\beta)\overline{D}_i^L - \frac{\left(\rho_i^L\right)^2}{2}\end{aligned} \quad (4)$$

where

ρ_i^L and ρ_j^L are the probabilities of individual innovation
$\underline{D}_i^L$ is the firm i's profit whet it play as licensee
$\overline{D}_i^L$ is the firm i's profit whet it play as licensor

In the case of a two-part license, licensor (i) and licensee (j)'s profit functions are the following:

$$\overline{D}_i^L = (1 - q_i - q_j)q_i + rq_j + L \quad (5)$$
$$\underline{D}_j^L = (1 - q_i - q_j)q_j - rq_j - L \quad (6)$$

Notice that the introduction of the per-unit royalty r increases the licensee's marginal cost and the licensor's marginal revenue, affecting the Cournot equilibrium.

We derive the optimal two-part tariff by backward induction, maximizing the licensor's profits, under the licensee's participation constraint; i.e., the licensee has to obtain at least the non-cooperative case profits.

Lemma 1 *The optimal two part tariff is characterized by a zero fixed-fee, $L = 0$, and a per-unit royalty equal to the pre-innovation marginal cost, $r = c$.*
Proof *In Appendix.*

According to Lemma 1, the profits in Equations (5) and (6) become:

$$\underline{D}^L = \underline{D} = \left(\frac{1-2c}{3}\right)^2$$
$$\overline{D}^L = \frac{1-5c^2+5c}{9}$$

Comparing expected profits (1) and (4), we obtain the following proposition.

Proposition 4. *In terms of expected profits, the licensing case dominates the non-cooperative one; i.e., $\forall (\beta, c) \subset [0,1] \times [0, 0.5]$, $\Pi^L > \Pi^N$.*

Proof. In Appendix. ■

Proposition 4 highlights that the licensing option guarantees higher profits to the innovator and does not affect licensee's ones. This means that firms prefer to sign a licensing agreement, when possible. The previous proposition leads to the following corollary.

Corollary 1 *Comparing the scenarios L and N, for any c and β:*
- $\rho^L > \rho^N$;
- $E^L > E^N$.

When firms can license the innovation, R&D investment increases, such as the probability of innovation. The intuition of the previous result is the following. For a given level of ρ, profits in Equations (1) and (4) differs in the two states of nature where one firm innovates and no imitation occurs. In these cases, licensing gives higher profit; thus, the marginal benefit of an increase in ρ is higher. As a consequence, in equilibrium, each firm invests more when licensing is possible.

In the last raw of Tables 1 and 2, we report equilibrium values of per-firm expected profit, industry R&D expenditure and probability of innovation, in the case of licensing.

5.1. *The equilibria of the game with licensing*

According to Propositions 1 and 4, the relevant comparison involves the scenarios C and L, whose equilibrium outcomes are presented in Table 2. This allows us to state the following propositions:

Proposition 5. *There exists a set*

$$L_1 \cup L_2 \equiv \left\{(\beta, c) \subset [0,1] \times [0,0.5] : \Pi^L \geq \Pi^C\right\}$$

such that R&D Competition with licensing achieves the highest level of per-firm profits; i.e. $\Pi^L = MAX\left[\Pi^J, \Pi^C, \Pi^L\right]$;

there exists a complementary set

$$W \equiv \left\{(\beta, c) \subset [0,1] \times [0,0.5] : \Pi^C \geq \Pi^L\right\}$$

such that R&D Cartelization achieves the highest level of per-firm profits; i.e., $\Pi^C = MAX\left[\Pi^J, \Pi^C, \Pi^L\right]$.

Proof. In Appendix. ■

Proposition 6. *There exists a set*

$$L_1 \equiv \left\{(\beta, c) \subset [0,1] \times [0,0.5] : \ \beta \leq \frac{72 + 160c - 474c^2 + 233c^3}{90 + 151c - 474c^2 + 233c^3} = \beta_1\right\}$$

such that R&D Competition achieves the highest level of industry R&D expenditure and probability of innovation; i.e. $E^L = MAX\left[E^J, E^C, E^L\right]$ *and* $P^L = MAX\left[P^J, P^C, P^L\right]$;

there exists a complementary set

$$L_2 \cup W \equiv \{(\beta, c) \subset [0,1] \times [0,0.5] : \beta > \beta_1\}$$

such that R&D Cartelization achieves the highest level of industry R&D expenditure and probability of innovation; i.e., $E^C = MAX\left[E^J, E^C, E^L\right]$ *and* $P^C = MAX\left[P^J, P^C, P^L\right]$.

Proof. In Appendix. ■

Figure 2 illustrates Propositions 5 and 6. The introduction of licensing modifies the firms' incentives to cooperate and invest in R&D. Licensing increases R&D returns appropriability and enlarges the parameter set where R&D Competition leads to the highest profits with respect to the alternative scenarios (Area $L_1 \cup L_2$). Licensing has an analogous impact on the industry R&D expenditure and the probability of innovation. In Area L_1 competition guarantees the highest level of industry R&D investment and probability to innovate, while in Area $L_2 \cup W$ cooperation enhances the innovation outcomes.

In Area L_1, the market equilibrium is efficient, since competing in R&D maximizes industry R&D investments and probability of innovation. Analogously, in Area W, R&D cooperation emerges in equilibrium, leading to the highest innovation outcomes. The inefficient equilibrium is the one in Area L_2,where competition emerges in equilibrium but cooperation leads to a better social outcome; only in this case, cooperation needs incentives.

In terms of policy implication, licensing is a market instrument to reduce the public intervention. Indeed, with respect to the non-licensing case, there are not cases where cooperation emerges spontaneously even though it is inefficient (Area A_1 in Figure 1), and a public intervention is required only to boost cooperation for intermediate levels of spillovers (Area L_2 in Figure 2). In other words, only in Area L_2, public intervention to boost cooperation increases innovative performance, while in Area L_1, in presence of licensing, the same policy represents a waste of public resources.

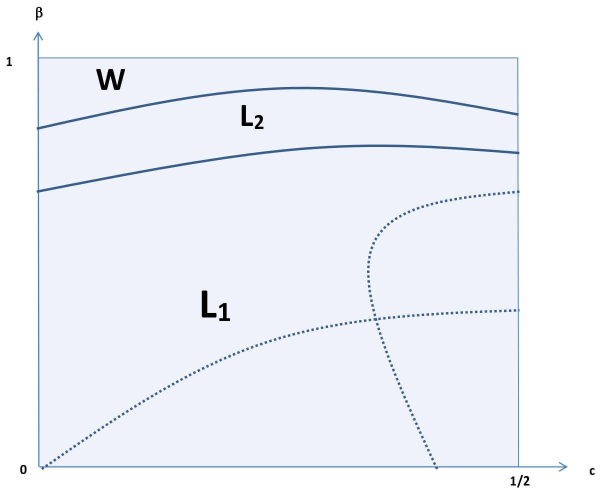

Figure 2. The equilibria of the game with licensing.

6. Conclusion

Licensing is a profitable instrument to exploit innovation, increasing R&D return appropriability. Indeed, as Spulber (2016) points out, 'total worldwide royalty payments for IP (patents, trademarks, and copyrights) exceed 289 billion'. However, the literature on the impact of licensing on R&D cooperation is scant. In this paper we filled this gap, proposing a theoretical model of stochastic cost-reducing innovation. We evaluated the private incentive to cooperate in three different scenarios (R&D Cartelization, RJV Cartelization, and R&D Competition) in terms of expected profits, industry R&D expenditure and probability of innovation. In this framework, we introduced licensing as an additional instrument that firms can use to commercially exploit innovation, and analyzed its impact on market equilibria and efficiency. We showed that the introduction of licensing increases return appropriability, stimulates R&D Competition and investment, reducing the cases where public intervention is needed.

Our analysis can be seen as a first step towards understanding how licensing contracts affect R&D decision and the efficacy of policy instruments, boosting R&D cooperation. In our framework, the need for public intervention is reduced, because licensing itself increases the profitability of the non-cooperative scenario stimulating both industry R&D expenditure and the probability to achieve innovation. In other words, boosting cooperation risks to be a waste of public funds. Indeed, in order to stimulates additional R&D investments, governments should investigate the correct magnitude of spillovers and differentiate incentives according to industries' characteristics and the effectiveness of licensing. Unfortunately, most public policies for boosting innovation do not seem to consider this criterion for allocating funds.

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Appendix

Proof of Proposition 1

We use pairwise comparisons. First, we compare the R&D expenditures in the cases C and J: $E^J - E^C = \frac{2c^2(2-c)^2}{81} - \frac{(2c^2-4c)^2}{(-2c^2+4c+9)^2} = \frac{2(2-c)^2(-81+72c-20c^2-16c^3+4c^4)c^2}{81(2c^2-4c-9)^2} < 0$, $\forall c \in \mathbb{R}$. Since $E^C > E^J$, we compare the R&D expenditures in the cases C and N: $E^C - E^N = \frac{(2c^2-4c)^2}{(-2c^2+4c+9)^2} - \frac{(2\beta+c\beta-4)^2c^2}{(5c^2\beta-4c^2-2c\beta-9)^2} > 0$ iff $\beta > \beta_0 = \frac{34c-24c^2+8c^3}{25c-24c^2+8c^3+18}$.

Proof of Proposition 2

We use pairwise comparisons. First, we compare the industry probability of innovation in the cases C and J: $P^J - P^C = \frac{2}{9}c\,(2-c) - 4c\,(c-2)\,\frac{-2c+c^2-9}{(-4c+2c^2-9)^2} < 0$, $\forall c \in \mathbb{R}$. Since $P^C > P^J$, we compare P^C and P^N: $P^C - P^N = 4c\,(c-2)\,\frac{-2c+c^2-9}{(-4c+2c^2-9)^2} - c\left(4c - 6c\beta + 9c^2\beta - 8c^2 - 18\right)\frac{2\beta+c\beta-4}{(-2c\beta+5c^2\beta-4c^2-9)^2} > 0$ iff $\beta > \beta_0 = \frac{34c-24c^2+8c^3}{25c-24c^2+8c^3+18}$.

Proofs of Proposition 3.

It follows the same pairwise comparisons used in the proofs of Propositions 1 and 2.

Proof of Proposition 4

First, we compute the Cournot Nash equilibrium. From Equations 5 and 6, we obtain $\overline{D}^L = \left(-\frac{1}{9}\right)\left(5r^2 - 5r - 1\right) + L$ and $\underline{D}^L = \frac{1}{9}\left(2r-1\right)^2 - L$. Second, we maximizes $\overline{D}^L$ with respect to r and L, under the constraint $\underline{D}^L \geq \underline{D} = \left(\frac{1-2c}{3}\right)^2$. Thus, $\frac{\partial \overline{D}^L}{\partial r} = \frac{1}{9} - \frac{2}{9}r = 0 \Rightarrow r = \frac{1}{2}$. Substituting $r = \frac{1}{2}$ in the licensee's constraint we obtain $L = -\left(\frac{1-2c}{3}\right)^2 < 0$ (impossible). Thus, setting $L = 0$, we obtain from the licensee's constraint the optimal level of r : $\frac{1}{9}\left(2r-1\right)^2 - \left(\frac{1-2c}{3}\right)^2 = 0 \Rightarrow r = c$.

Proof of Proposition 5

It follows from the comparisons of expected profits in cases L and N reported in Table 1.

Proof of Propositions 6 and 7

They follow the same pairwise comparisons used in the proofs of Propositions 1 to 3.

Scenarios	Expected per-firm profit (Π)
R&D Cartelization	$\frac{9-18c+13c^2-4c^3+c^4}{81}$
R&D Cooperation	$\frac{1}{9}\frac{9-14c+7c^2}{4c-2c^2+9}$
R&D Competition	$\frac{324-162c-56c^2\beta^2-120c^3\beta^2-16c^3\beta^3+98c^4\beta^2-8c^5\beta^2+12c^5\beta^3-40c^6\beta^2+4c^6\beta^3}{9(9+2c\beta-5c^2\beta+4c^2+9)^2}+\frac{144c\beta-252c^2\beta+192c^3\beta-39c^4\beta-20c^5\beta+68c^6\beta+54c^2-36c^3-64c^4+16c^5-32c^6}{9(9+2c\beta-5c^2\beta+4c^2+9)^2}$
R&D Competition with licensing	$-\frac{36c-252c^2\beta^2-1196c^3\beta^2-480c^3\beta^3+8053c^4\beta^2-1760c^4\beta^3-2560c^5\beta^2+6360c^5\beta^3-55\,070c^6\beta^2+6280c^6\beta^3+138\,100c^7\beta^2}{18(-8c+6c\beta+19c^2\beta-50c^3\beta+25c^4\beta-18c^2+50c^3-25c^4-9)^2}+-\frac{-37\,200c^7\beta^3-147\,075c^8\beta^2+46\,800c^8\beta^3+75\,000c^9\beta^2-25\,000c^9\beta^3-15\,000c^{10}\beta^2+5000c^{10}\beta^3+216c\beta+1380c^2\beta}{18(-8c+6c\beta+19c^2\beta-50c^3\beta+25c^4\beta-18c^2+50c^3-25c^4-9)^2}+-\frac{1944c^3\beta-10\,330c^4\beta-13\,560c^5\beta+91\,200c^6\beta-164\,600c^7\beta+153\,750c^8\beta-75\,000c^9\beta}{18(-8c+6c\beta+19c^2\beta-50c^3\beta+25c^4\beta-18c^2+50c^3-25c^4-9)^2}+-\frac{15\,000c^{10}\beta-1226c^2-296c^3+4044c^4+9760c^5-42\,410c^6+63\,700c^7-53\,475c^8+25\,000c^9-5000c^{10}-162}{18(-8c+6c\beta+19c^2\beta-50c^3\beta+25c^4\beta-18c^2+50c^3-25c^4-9)^2}$

Table 1. Per-firm expected profits.

Scenarios	Industry R&D Expenditure (E)	Probability to Innovate (P)
R&D Cartelization	$\frac{2c^2(2-c)^2}{81}$	$\frac{2c(2-c)}{9}$
R&D Cooperation	$\frac{(2c^2-4c)^2}{(9-2c^2+4c)^2}$	$\frac{4(c^2-2c-9)(c-2)c}{(2c^2-4c-9)^2}$
R&D Competition	$\frac{(2\beta+c\beta-4)^2c^2}{(5c^2\beta-4c^2-2c\beta-9)^2}$	$\frac{c(4c-6c\beta+9c^2\beta-8c^2-18)(2\beta+c\beta-4)}{(-2c\beta+5c^2\beta-4c^2-9)^2}$
R&D Competition with licensing	$\frac{(10\beta-14c+15c\beta+50c^2-25c^3-50c^2\beta+25c^3\beta-12)^2c^2}{2(6c\beta-8c-18c^2+50c^3-25c^4+19c^2\beta-50c^3\beta+25c^4\beta-9)^2}$	$1-\left(1-c\frac{10\beta-14c+15c\beta+50c^2-25c^3-50c^2\beta+25c^3\beta-12}{6c\beta-8c-18c^2+50c^3-25c^4+19c^2\beta-50c^3\beta+25c^4\beta-9}\right)^2$

Table 2. Industry R&D expenditures and Industry probability to innovate.