Spillovers, Product Innovation and R&D Cooperation: a Theoretical Model

Carlo Capuano, Iacopo Grassi

**Abstract** In this paper, we deal with the impact of post-innovation knowledge spillovers on private firms decisions to invest in R&D and cooperate, forming a Research Joint Venture (RJV). In particular, we analyze the case of two potential investors involved in a non-tournament competition for a stochastic product innovation in a market where imitation is possible, proposing a theoretical model where cooperation may emerge as subgame perfect Nash equilibrium of a three stage game: in the first stage, firms decide whether cooperate or not; in the second, they decide whether invest on; in the third, they compete in the market. We show that firms cooperate in R&D when spillovers are high enough and the fixed costs associated to R&D activities are low enough; however, our analysis suggests that cooperation in R&D may not always be optimal and, as a consequence, subsidizing any form of R&D cooperation is not efficient. Starting from the equilibria of the game, we propose an optimal scheme of subsides, which should be designed according to the intensity of spillovers, the level of R&D costs, and the probability to succeed in innovation. Finally, when we introduce collusion in the market stage, the private incentive to invest increases, reducing the cases where firms need public subsidies to cooperate in R&D. When subsides are costly tolerating collusion may be a second best solution.

**JEL classification** H2 · L1 · L5

**Keywords** R&D · cooperation · spillovers · RJV · subsides · collusion

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1 Introduction

In the last decades, Economic literature has deeply analyzed the causes and the effects of R&D cooperation with a huge amount of researches studying how, why and with whom firms may collaborate.\(^1\)

A significant proportion of contributions tries to incorporate the impact of spillovers in R&D activities in the analysis; according to d’Aspremont and Jacquemin (1988), ”the R&D externalities or spillovers imply that some benefits of each firm’s R&D flow without payment to other firms” (pg. 1133). In process innovation, spillovers are positive production externalities that reduce costs for all the firm in the market; in product innovation, they allow firms that did not innovate to imitate the new good and to compete in the market. In both cases, firms in the industry obtain costless advantages from competitors’ R&D activities. On the one hand, spillovers increase the diffusion speed of innovation, on the other the same spillovers reduce R&D returns appropriability, and induce firms to under-invest with respect to the social optimum; hence, there is room for public interventions using, for example, direct subsides to R&D or subsides to cooperation in R&D, boosting R&D investment through collaboration.

The large majority of theoretical models dealing with R&D cooperation and spillovers, assume oligopolistic firms playing a two stage game: in the first stage firms choose R&D levels cooperatively or non-cooperatively, and in the second stage they play price or quantity competition. One of the seminal contribution is d’Aspremont and Jacquemin (1988), where authors, comparing three different scenarios in process innovation (competition in both the stages, cooperation just in the R&D stage and cooperation in both the stage - hence collusion in the market stage), find that, for spillovers high enough, cooperative R&D increases profits and social welfare. Kamien et al. (1992) introduce in the analysis product differentiation and RJV cartelization, enlarging the set of parameters such that cooperation is the social optimum. Other contributions in Choi (1993), Leahy and Neary (1997), Goyal and Moraga-Gonzalez (2001), under slightly different model setting, confirm these results. Furthermore, some authors have suggested the idea that firms may use the cooperation in R&D stage to better coordinate their actions and collude in the final market competition stage.\(^2\) The stake of collusion increases firms incentive to cooperate and invest in R&D, even though allocative efficiency is reduced.

Our paper is positioned within this literature, dealing with the case of product innovation in markets where imitation is possible.\(^3\) In particular, we analyze the impact of post-innovation knowledge spillovers on private firms’ decisions to invest in R&D and cooperate forming a Research Joint Venture (RJV), that is the form of collaboration in R&D that firms prefer.\(^4\) We focus on the case that Kamien et al.

\(^1\) For a general survey on R&D cooperation see Marinucci (2012); for a survey of the empirical literature on public R&D policies see Becker (2015).

\(^2\) This scenario was first assumed in the seminal contribution by d’Aspremont and Jacquemin (1988); other papers on this topic are Martin (1995), Cabral (2000), Lamberti et al. (2003), Cabon-Dhersin (2008), Miyagawa (2009), Yao and Zheng (2014).

\(^3\) This could be, for example, the case of IT companies that compete for producing and selling new software or new hardware: ascertained the effectiveness of the new product, in a relatively short time there is a significant risk that innovation is imitated by competitors.

\(^4\) Although results may differ according to sample size or to source, empirical literature does lead to some conclusion concerning the causes of R&D cooperation; for example, there is empirical evidence that one of the main objectives of R&D cooperation is R&D cost sharing, and that RJV is the preferred form of cooperation. See, inter alia, Veugelers and Kesteloot (1994), Hagedoorn and Schakenraad (1994), Tao and Wu (1997), Caloghirou et al. (2003). A survey on the empirical findings on the forms of cooperation is in Silipo (2008).
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(1992) define "RJV cartelization": when firms cooperate in R&D, they coordinate their R&D activities, maximizing the sum of the expected profits, sharing efforts and avoiding duplication of R&D research lines; in the market stage, firms compete.

Our paper contributes to the theoretical literature introducing several elements of novelty.

First, we focus on stochastic product innovation with spillovers, while most of the literature analyzes the case of marginal cost-reducing innovation. According to the Eurostat’s Community Innovation Survey (2006-2008), over the 28% of the innovating firms are involved in product innovation, and about 63% of them cooperate with competitors, when they are developing new goods or services. These data confirm the relevance of the theoretical analysis proposed in our article.

Second, we study R&D cooperation decision in a three stage game, while all previously cited theoretical contributions compare two scenarios (not cooperation in R&D versus cooperation) in a two stages game, where the choice to cooperate is exogenously given. Adding a preemptive stage where cooperation is an endogenous decision, we prove that cooperation does not always emerges in equilibrium and firms collaborate in R&D only when spillovers are high enough and the fixed costs associated to R&D activities are low enough.

Third, we propose an optimal scheme of subsidies to R&D cooperation; despite the increasing number of public programs to boost competitiveness of firms subsidizing R&D cooperation, the theoretical literature on this kind of subsidies is practically non-existing. Our analysis shows that, contrary to seminal literature on R&D and spillovers, forming an RJV may not be the social optimum because, if, on the one hand, sharing the costs firms reduce the investment risk, on the other hand, collaboration reduces the probability to innovate in the market, since cooperating through RJV halves the research lines. As a consequence, subsidizing R&D cooperation is not always efficient; we show that, when it emerges in equilibrium of the game, cooperation is efficient, hence subsides would be a waste of public funds; however, there are cases where cooperation is efficient but does not emerges (subsidies are necessary) and cases where cooperation is not efficient and does not emerge (subsidy are not necessary). In our analysis, we propose an optimal subsidy scheme, designed according to the intensity of spillovers, the level of R&D costs, and the probability to succeed in innovation. Our model suggests that subsidies to R&D cooperation have to be higher in markets where the industry research is characterized by lower levels of spillovers, this could be the case in industry mostly involved in high-tech research. Belleflamme and Peitz (2010) state a negative relationship between spillovers and patent pro-

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5 To the best of our knowledge, the only other paper analyzing the equilibria in a three stage game is Silipo and Weiss (2005), where the authors compare equilibria under different kinds of cooperation concluding that RJV leads to more investment, profits and social welfare; differently from us, they do not consider the role of Government and the subsides, do not allow collusion in the market stage, and assume that spillovers may enlarge the profits of the industry.

6 For example, in the last years, just in Europe, there have been the programs ESPRIT, IST, EUREKA! and many more national programs finalized to increase R&D cooperation.

7 However, there are some theoretical contributions on subsidies to investment in R&D: Hinloopen (1997, 2000) compares the effect of cooperating in R&D with the one of subsidies to investment in R&D, showing that in general the latter policy is more effective in promoting R&D; Leahy and Neary (1997) present a general analysis of the effect of strategic behavior and cooperative R&D in the presence of price and output competition. They also study optimal public policy towards R&D in the form of subsidies, concluding that RJV should not receive subsidies; Rebolledo and Sandonis (2010) show that R&D subsidies may hurt subsidized firms, in case of international oligopolistic competition and asymmetric information among firms on whether a rival is being subsidized.

8 See, for example, Kamien et al. (1992) where, for any spillover rate, RJV (cartelization) is the form of R&D cooperation that provides the largest level of R&D investment and the lowest level of price in the final market.
tection, assuming that the latter is higher in R&D intensive industries. In fact, they affirm: “Spillover levels vary drastically across industries. They are often inversely related to the level of patent protection. For instance, low-tech mature industries (e.g., paper) exhibit low effective patent protection and, hence, high spillovers; conversely, R&D intensive industries (e.g., such as pharmaceutical drugs and software) exhibit high effective patent protection and low spillovers” (pg. 492). Implicitly, our model predicts that cooperation in form of RJV hardly emerges when the spillovers are low, i.e. when patent protection is high. This results gives a theoretical explanation to empirical evidences proposed by Hernan et.al (2003); using a large data-set on RJV, they find that patents effectiveness reduce R&D cooperation, empirically confirming that low spillovers are detrimental to cooperation. In Europe, the main policy instrument to promote R&D investment is the European Framework Programme (FP). Public funds are usually given after that competing projects are judged by a pool of experts, and the projects must fulfill criteria that represent the objective targets of EU, for example promoting a specific sector or kind of investment. Most of the European subsides are formally subsides to direct investment in R&D and not to cooperation in R&D; nevertheless, they often require cooperation as necessary condition to apply to the funds, boosting formal collaboration. However, the levels of funds provided do not depend on market spillovers, but on policy decisions.  

Finally, in the last part of the paper, we assume that cooperation in the first stage leads to collusion in the market stage; we analyze the impact of collusion in terms of welfare when subsidies are costly to taxpayers and there exists a (positive) shadow cost of public funds. Since collusion increases the private incentive to collaborate and invest in R&D, it reduces the cases where firms need subsidies to cooperate. Even if collusion reduces the allocative efficiency of the market, costly subsidies may lead to even worse outcomes; in this case, tolerate collusion may be a second best solution.  

The paper is organized as follows: in Section 2 we present the model and analyze the SPNE of the game, focusing on the case where cooperation in R&D emerges in equilibrium; Section 3 analyzes the public incentives to invest in R&D; Section 4 introduces the case where firms collude in the market stage; public policy implications and conclusions are discussed in Sections 5.

2 The model

2.1 Model setting

Following the framework illustrated in Belleflamme and Peitz (2010), we consider the case of \( n = 2 \) firms, \( i \) and \( j \), as potential investors in a non-tournament stochastic product R&D process: each firm decides whether to bear or not a fixed cost \( f > 0 \), in order to produce an innovative good with probability \( \rho \in [0, 1] \). We assume that

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9 National or regional subsides to cooperation exist, and in this case the possibility that they are a sort of indiscriminate, all-round distribution, according to local policy objective may be higher.

10 This theoretical results is coherent with Goere and Helland (2009)'s empirical evidences stating that stricter antitrust rules on R&D cooperation may reduce the probability that firms will create RJVs.

11 See pages 490-492.

12 R&D literature distinguishes between tournament and non-tournament models. In tournament models, the first competitor to succeed is the only one to remain in the market: it is a winner takes all competition and the innovator becomes monopolist in the market of the new product. In non-tournament model, competitors are not engaged in a race, there is not a winner and all players can succeed, innovate and compete in the market.

13 The probability of success associated to the fixed cost \( f \) is exogenous, equal for both firms and independent on the number of competing investors.
post innovation knowledge spillovers may allow not innovating firm to imitate the innovative good and enter the new market, with probability \( \beta \in [0, 1] \). Hence, we have a duopoly either when both firms innovate or one innovates and the other imitates. We assume full-information, symmetry between firms and simultaneous playing in each stage.

The timing of the game is the following:

- At stage \( t = 0 \), each firm decides if cooperate or not in R&D (furthermore, we denote the two cases by the indexes \( C \) and \( NC \)). We assume that, when firms cooperate, investment decisions are observable (full commitment), i.e. opportunistic behaviors and free riding are not possible.

- At stage \( t = 1 \), each firm decides if invest or not in R&D (furthermore, \( I \) and \( NI \)). If firms cooperate, they form a RJV, i.e. they finance the research sharing the fixed cost \( f \), internalize spillovers (\( \beta = 1 \)), and jointly patent innovations; if firms do not cooperate, they choose simultaneously and non-cooperatively whether to invest or not in R&D.

- At stage \( t = 2 \), firms observe the outcome of the innovation process, take advantage of spillovers and compete in the market.

Figure 1 describes the timing of the game.

Figure 1 The timing of the game

Hereafter, we denote by \( E \Pi_{i}^{z}(x_{i}; x_{j}) \) the expected profits of firm \( i \) where \( x_{i} \in \{I; NI\}, \) and \( z \in \{C; NC\} \), by \( \Pi^{M} \) and \( \Pi^{D} \) the monopoly and duopoly profits before
fixed costs $f$ (where $\Pi^M \geq 2\Pi^D$)\textsuperscript{14} and by $W^M$ and $W^D$ the social welfare before fixed costs in the two markets configurations (where $W^D \geq W^M$ and $W^D < 2W^M$).\textsuperscript{15}

We look for the subgame perfect Nash equilibria (SPNE), solving the game by backward induction: the subgame perfection requires that at $t = 2$, if only one firm can produce the new good, she plays monopoly; if both firms can produce the good, innovating or imitating, they play duopoly. This means that per-period profits of monopoly or duopoly are unaffected by previous decisions.

2.2 The non-cooperative subgame.

If firms do not cooperate in R&D, we have four possible outcomes: both firms invest, $(I; I)$, only one firm invests, $(I; NI)$ or $(NI; I)$, and no firm invests, $(NI; NI)$.

We start from the case where both firms $i$ and $j$ invest in R&D, spending $f$. With probability $\rho$ firm $i$ innovates. In such a case: with probability $\rho$ firm $j$ innovates as well, firms share the market achieving duopolistic profit $\Pi^D$. With probability $1 - \rho$ firm $j$ does not innovate. In this subcase: with probability $\beta$ spillovers allow firm $j$ to imitate the new good and enter the market achieving the duopolistic profit $\Pi^D$; otherwise, with probability $1 - \beta$ firm $i$ is the only one producing the new good obtaining the monopolistic profit $\Pi^M$. Conversely, with probability $1 - \rho$ firm $i$ does not innovate. In such a case: with probability $1 - \rho$ neither firm $i$ innovates and both firms achieve zero profits; with probability $\rho$ firm $j$ innovates. In this subcase: with probability $\beta$ spillovers allow firm $i$ to imitate the new good and enter the market achieving the duopolistic profit $\Pi^D$; otherwise, with probability $1 - \beta$ firm $j$ is monopolist and firm $i$ obtains zero profit. In other words, firm $i$ obtains the duopolistic profit $\Pi^D$ when both firms innovate (with probability $\rho^2$) or one innovates and the other imitates (with probability $2(1 - \rho)\beta$); firm $i$ obtains the monopolistic profit $\Pi^M$ when she is the innovating one and the other cannot imitate (with probability $\rho(1 - \rho)(1 - \beta)$); otherwise, she obtains zero profit. Therefore, the expected profit of firm $i$ is:

$$E\Pi_{iNC}(I; I) = \rho[\rho + 2(1 - \rho)\beta]\Pi^D + \rho(1 - \rho)(1 - \beta)\Pi^M - f$$ \hspace{1cm} (1)$$

Consider now the case where firm $j$ invests in R&D but firm $i$ does not: firm $j$ innovates with probability $\rho$ and spillovers occur with probability $\beta$; hence, firm $i$ expected profit is:

$$E\Pi_{iNC}(NI; I) = \rho\beta\Pi^D$$ \hspace{1cm} (2)$$

On the contrary, if firm $i$ invests in R&D and firm $j$ does not, the former innovates with probability $\rho$. In such a case, with probability $\beta$ firms share the market achieving the duopolistic profit $\Pi^D$; with probability $1 - \beta$ firm $i$ is monopolist obtaining $\Pi^M$. Hence, we have:

$$E\Pi_{iNC}(I; NI) = \rho[\beta\Pi^D + (1 - \beta)\Pi^M] - f$$ \hspace{1cm} (3)$$

If firms do not invest in R&D, no innovation occurs and the expected profit is null. We have:

$$E\Pi_{iNC}(NI; NI) = 0$$ \hspace{1cm} (4)$$

Table 1 summarizes these results.

\textsuperscript{14} We assume equal duopoly profits: removing this hypothesis affects only the threshold values of the parameters that characterize the different SPNE of the game, but not the number and types of the SPNE.

\textsuperscript{15} It is easy to show that the latter condition implies that $W^D - W^M < W^M$ and it is always true in the linear cases.
In order to obtain the equilibrium of the non-cooperative subgame, we compute the per-firm incentives to innovate, $f_1$ (when only one firm invest) and $f_2$ (when both firms invest). For any possible decisions of the rival at $t = 1$ both incentives are computed as the threshold levels of the fixed cost $f$ that, in equilibrium, makes one firm indifferent between investing or not.

At time $t = 1$, each firm plays her best reply to the possible actions rival can play (investing or not). Consider the case where firm $j$ does not invest in R&D. We denote by $f_1$ the incentive of firm $i$ to be the only one to invest: it is equal to the maximum level of the fixed cost $f$ such that the expected profit of firm $i$ is non-negative ($E\Pi_{NC}^i (I; NI) \geq 0$, participation constraint) and non-lower than her expected profit when she does not invest ($E\Pi_{NC}^i (I; NI) \geq E\Pi_{NC}^i (NI; NI)$, incentive compatibility constraint). Since not investing firm $i$ obtains expected profit equal to zero, both constraints are binding; we obtain:

$$f_1 = \rho \left( \beta \Pi^D + (1 - \beta) \Pi^M \right)$$  \hspace{1cm} (5)

Using equation 5, we can write the expected profit of firm $i$ expressed in equation 3 as a function of $f_1$, obtaining:

$$E\Pi_{NC}^i (I; NI) = f_1 - f$$  \hspace{1cm} (6)

Analogously, assume now that firm $j$ invests in R&D. We denote by $f_2$ the incentive of firm $i$ to invest as well: it is equal to the maximum level of the fixed cost $f$ such that the expected profit of firm $i$ is not negative ($E\Pi_{NC}^i (I; I) \geq 0$, participation constraint) and non-lower than her expected profit when she does not invest ($E\Pi_{NC}^i (I; I) \geq E\Pi_{NC}^i (NI; I)$, incentive compatibility constraint). In this case, not investing firm $i$ obtains positive expected profit taking advantage of spillovers and the incentive compatibility constraint is binding; we obtain:

$$f_2 = \rho \Pi^M - \rho^2 (\Pi^M - \Pi^D) - \beta (\rho (1 - \rho) (\Pi^M - 2\Pi^D) + \rho \Pi^D)$$  \hspace{1cm} (7)

Using equation 7, we can write the expected profit of firm $i$ expressed in equation 1 as a function of $f_2$, obtaining:

$$E\Pi_{NC}^i (I; I) = f_2 + \rho \beta \Pi^D - f$$  \hspace{1cm} (8)

Note that the incentive to invest when the other does not ($f_1$) is always higher than the one computed assuming the rival invests ($f_2$):

$$\Delta f = f_1 - f_2 = \rho \beta (1 - \beta) (\Pi^M - \Pi^D) + \beta \rho^2 \Pi^D > 0$$  \hspace{1cm} (9)

This occurs because, for the same level of per-firm investment, the probability to be monopolist is higher when only one firm invests.
Moreover, in both cases (either one or two firms invest) spillovers reduce the private incentive to innovate:

\[ f_2 = f_2|_{\beta=0} - \beta (\rho (1-\rho)(I^M - 2I^D) + \rho I^D) \]

\[ \frac{\partial f_2}{\partial \beta} = - (\rho (1-\rho)(I^M - 2I^D) + \rho I^D) < 0 \]

and

\[ f_1 = f_1|_{\beta=0} - \beta(I^M - I^D) \]

\[ \frac{\partial f_1}{\partial \beta} = -\beta(I^M - I^D) < 0 \]

Using definitions 5 and 7, we can state the following Proposition:

**Proposition 1** At \( t = 1 \), the following vectors of actions are part of the SPNE of the non-cooperative subgame:

- (a) \((NI; NI)\) for any \((\beta; f)\) ∈ \([0, 1] \times \mathbb{R}^+: f > f_1\);
- (b) \((I; NI)\) or \((NI; I)\) for any \((\beta; f)\) ∈ \([0, 1] \times \mathbb{R}^+: f_2 < f \leq f_1\);
- (c) \((I; I)\) for any \((\beta; f)\) ∈ \([0, 1] \times \mathbb{R}^+: f \leq f_2\).

**Proof** — Suppose firm \( j \) does not invest in R&D, firm \( i \) does not invest in R&D as well, if and only if \( EII_{NC}^i (NI; NI) \geq EII_{NC}^i (I; NI) \), that is \( EII_{NC}^i (I; NI) \leq 0 \); using equation 6 this is true if and only if \( f_1 - f \leq 0 \), i.e. \( f \geq f_1 \).

- Suppose firm \( j \) does not invest in R&D, firm \( i \) does invest in R&D, if and only if \( EII_{NC}^i (I; NI) \geq EII_{NC}^i (NI; NI) \), that is \( EII_{NC}^i (I; NI) \geq 0 \), using equation 6 this is true if and only if \( f_1 - f \geq 0 \), i.e. \( f \leq f_1 \); in such a case, firm \( j \) does not deviate if and only if \( EII_{NC}^i (NI; I) \geq EII_{NC}^i (I; I) \), using equations 2 and 8 this is true if and only if \( \rho \beta I^D \geq f_2 + \rho \beta I^D - f \), i.e. \( f \geq f_2 \).

- Suppose firm \( j \) does invest in R&D, firm \( i \) does invest in R&D as well, if and only if \( EII_{NC}^i (I; I) \geq EII_{NC}^i (NI; I) \), using equations 2 and 8 this is true if and only if \( f_2 + \rho \beta I^D - f \geq \rho \beta I^D \), i.e. \( f \leq f_2 \).

Proposition 1 states that the choice to invest in R&D depends on the fixed cost \( f \): if it is high enough, no firm invests; if it is low enough, both firms invest; for intermediate values of \( f \) only one firm invests.\(^{16}\)

2.3 The cooperative subgame

When firms cooperate they form a RJV and sign a full-commitment agreement, excluding any sort of free-riding or opportunistic behavior. They unanimously decide whether invest or not in R&D and we have only the two symmetric outcomes as possible, \((I; I)\) and \((NI; NI)\): when they decide to invest, firms share the R&D cost \( f \) associated to the joint line of research (no duplication of fixed costs). In case of innovation, they fully internalize the spillovers (\( \beta = 1 \)) jointly patenting the new good, and obtain duopolistic profits in the market stage. Hence, the expected profit of firm \( i \) when the RJV invest in R&D is the following:

\[ EII_i^C (I; I) = \rho I^D - \frac{f}{2} \quad (10) \]

\(^{16}\) When \( f_1 \geq f > f_2 \) we have two vectors as part of the SPNE in pure strategies, \((I; NI)\) and \((NI; I)\). As a consequence the non-cooperative subgame admits an equilibrium in mixed strategies whose simple characterization is outside the scope of this work.
If the RJV does not invest in R&D, each firm obtains zero profits:

\[ E\Pi^C_i(NI; NI) = 0 \quad (11) \]

Table 2 illustrates these results.

**Table 2** Firm \( i \) expected profits, in the two possible outcomes of the cooperative subgame

<table>
<thead>
<tr>
<th>( I )</th>
<th>( \rho \Pi^D )</th>
<th>( NI )</th>
</tr>
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<tbody>
<tr>
<td>( I )</td>
<td>( f_C )</td>
<td>( 0 )</td>
</tr>
<tr>
<td>( NI )</td>
<td>( 0 )</td>
<td>( 0 )</td>
</tr>
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</table>

We denote by \( f_C \) the firm’s incentive to invest in R&D in the cooperative subgame. It is the maximum fixed cost \( f \) such that the cooperative expected profit of firm \( i \) (or \( j \)) is non negative \( (E\Pi^C_i(I; I) \geq 0) \).\(^{17}\) Hence, from equation 10 we have:

\[ f_C = 2\rho\Pi^D \quad (12) \]

Note that \( f_C \) does not depend on \( \beta \), since spillovers are fully internalized when firms cooperate \( (\beta = 1) \).

Using equation 12, we can write the expected profit of firm \( i \) expressed in equation 10 as a function of \( f_C \), obtaining:

\[ E\Pi^C_i(I; I) = \frac{f_C}{2} - \frac{f}{2} \quad (13) \]

Using equation 12, we can state the following Proposition:

**Proposition 2** At \( t = 1 \), investing in R&D is part of the SPNE of the cooperative subgame for any \( (\beta; f) \in [0, 1] \times \mathbb{R}^+ : f \leq f_C \).

**Proof** It follows from the non negativity condition on the expected profit \( E\Pi^C_i(I; I) \).

Proposition 2 asserts that, in the cooperative subgame, investing in R&D always emerges in equilibrium when the fixed cost \( f \) is low enough.

### 2.4 The extended game

At \( t = 0 \), firms compare expected profits associated to the SPNE of the alternative subgames (i.e. the non-cooperative and the cooperative ones). Hence, cooperation is part of the SPNE of the extended game if and only if, for each firm, the expected cooperation profits are not lower than the ones associated with the SPNE of the non-cooperative subgame. This allows us to state the following proposition:

**Proposition 3** At \( t = 0 \), cooperation is part of the SPNE of the extended game for any \( (\beta; f) \in [0, 1] \times \mathbb{R}^+ : f_C \geq f > \max \{ f_2; 2f_1 - f_C \} \cup \text{any} \ (\beta; f) \in [0, 1] \times \mathbb{R}^+ : \min \{ f_2; f_C \} \geq f \geq 2f_2 - (1 - \beta)f_C .\)

\(^{17}\) While in the non-cooperative subgame we derived the private incentives to invest considering both participation and incentive-compatible constraints, in the cooperative subgame these constraints coincide. This is because in the cooperative subgame firms have two alternatives: to invest jointly or not to invest at all. In the second case the expected profits are zero.
Proof — If \( f > f_1 > f_2 \text{and } f > f_C \), we have \( EII^{NC}_i(I;NI) < 0, EII^{NC}_i(I;I) < 0 \) and \( EII^{NC}_C(I;I) < 0 \); since \( EII^{NC}_i(N;NI) = 0 \), then at \( t = 0 \) firms do not cooperate and at \( t = 1 \) they do not invest.

- If \( f > f_1 > f_2 \text{and } f \leq f_C \), we have \( EII^{NC}_i(I;NI) < 0, EII^{NC}_i(I;I) < 0 \) and \( EII^{NC}_C(I;I) \geq 0 > EII^{NC}_i(I;I) \); then, at \( t = 0 \) firms cooperate and at \( t = 1 \) both invest.

- If \( f_1 \geq f > f_2 \text{and } f > f_C \), we have \( EII^{NC}_i(I;NI) \geq 0 > EII^{NC}_i(I;I) \) and \( EII^{NC}_i(I;I) < 0 \), then, at \( t = 0 \) firms do not cooperate and at \( t = 1 \) only one does invest.

- If \( f_1 \geq f > f_2 \text{and } f \leq f_C \), we have \( EII^{NC}_i(I;NI) \geq 0, EII^{NC}_i(I;I) < 0 \) and \( EII^{NC}_C(I;I) \geq 0 \); then, at \( t = 0 \) firms cooperate and at \( t = 1 \) they invest, if and only if \( EII^{C}_i(I;I) \geq EII^{NC}_i(I;NI) \). Using equations 6 and 13 this is true if and only if \( \frac{f_C}{f_1} - \frac{f_C}{f_2} \geq f_1 - f \), that is \( f \geq 2f_1 - f_C \).

- If \( f \leq f_2 \text{and } f > f_C \), we have \( EII^{NC}_i(I;I) \geq 0 > EII^{NC}_i(I;I) \); then, at \( t = 0 \) firms do not cooperate and at \( t = 1 \) both invest.

- If \( f \leq f_2 \text{and } f \leq f_C \), we have \( EII^{NC}_i(I;I) \geq 0 \) and \( EII^{NC}_i(I;I) \geq 0 \); then, at \( t = 0 \) firms cooperate if and only if \( EII^{C}_i(I;I) \geq EII^{NC}_i(I;I) \). Using equations 8 and 13 this is true if and only if \( \frac{f_C}{f_1} - \frac{f_C}{f_2} \geq f_2 + \rho \beta \Pi^D - f \), that is \( f \geq 2f_2 - (1 - \beta)f_C \); if \( \rho \leq \tilde{\rho} = \frac{n^m - 2m^n}{m^n - m^m} \) we have \( f_C \leq f_2 \) for \( \beta = 0 \); this implies that \( f \geq 2f_2 - (1 - \beta)f_C \) is never satisfied then, at \( t = 0 \) firms do not cooperate and at \( t = 1 \) both invest; conversely, if \( \rho > \tilde{\rho} \) the constraint \( f \geq 2f_2 - (1 - \beta)f_C \) is relevant to characterize the SPNE of the extended game; then, at \( t = 0 \) firms cooperate and at \( t = 1 \) both invest if and only if \( f \in \mathbb{R}^+ : f \leq f_C \text{ and } f \leq f_2 \text{ and } f \geq 2f_2 - (1 - \beta)f_C \).

Proposition 3 describes the combinations of parameters \( \beta \) and \( f \) where cooperation emerges as part of the equilibrium of the extended game. We have this result for high levels of \( \beta \) and intermediate values of \( f \): when the fixed cost is too high, investing in R&D is never profitable; when fixed cost is very low, firms prefer investing alone since the positive expected monopolistic profit (achievable only without cooperation) is larger than the saving from sharing fixed cost cooperating; for intermediate values of \( f \), the latter effect dominates the former and firms prefer to cooperate internalizing spillovers.

Figure 2 illustrates the different SPNE of the extended game when \( \rho \leq \tilde{\rho} \), i.e. the probability to innovate is not too high; hereafter, we concentrate the graphical analysis on this case. In area C cooperation emerges in equilibrium; in other areas firms do not cooperate: in area A firms do not invest, in area B just one firm invests, in area D both firms invest non-cooperatively.

3 Public evaluation of R&D

The aim of this Section is ranking the different outcomes of the extended game according to the levels of expected social welfare, \( EW \). We calculate the expected social welfare as the sum of consumer surplus and expected profits; its value depends on the equilibria investment decisions, the spillovers parameter \( \beta \), the probability of success \( \rho \) associated to investment in R&D and the level of welfare in duopoly \( W^D \) and monopoly \( W^M \) achieved at time \( t = 2 \).

Consider the non-cooperative subgame. Table 3 illustrates the expected social welfare, in the four possible cases.

Consider now the cooperative subgame; in case of joint investment the expected social welfare is given by:

\[
EW^C(I;I) = \rho W^D - f
\]  \( (14) \)
Fig. 2 The SPNE of the extended game.

Table 3 The expected social welfare

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>NI</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$\rho (\rho W_D + 2(1 - \rho)W_M^+ + 2(1 - \rho)(1 - \beta)W_M) - 2f$</td>
<td>$\rho (\beta W_D^+ + (1 - \beta)W_M) - f$</td>
</tr>
<tr>
<td>NI</td>
<td>$\rho (\beta W_D^+ + (1 - \beta)W_M) - f$</td>
<td>0</td>
</tr>
</tbody>
</table>

Otherwise, when the RJV does not decide to invest in R&D, the expected social welfare is given by:

$$EW^C (NI; NI) = 0$$  \hspace{1cm} (15)

The public value of cooperation $f_w$ is given by the maximum level of fixed cost $f$ such that the expected welfare when firm cooperates and the RJV invests in R&D is non-negative. Hence, we have:

$$f_w = \rho W_D^D$$  \hspace{1cm} (16)

The cooperative equilibrium leads always to the duopolistic market. Nevertheless, cooperation may not be the social optimum: as pointed out in Kamien et al. (1992), firms that form a RJV halve the per-firm cost of investing in R&D and reduce the research lines. As a consequence, the probability to innovate with respect to the case where both firms invest in R&D decreases ($\rho(2 - \rho) > \rho$), and the probability to have a monopoly in the market is zero. Hence, it may be the case that, for levels of $\beta$ high enough and levels of $f$ low enough, $EW^{NC} (I; I) \geq EW^C (I; I)$; we define $f_w$ the threshold value of the fixed cost $f$ such that $EW^{NC} (I; I) = EW^C (I; I)$. We have:
\[ \mathcal{f}_w = \rho(1 - \rho)[W^D - 2(1 - \beta)(W^D - W^M)] \]  

(17)

Using equations 16 and 17, we can state the following proposition:

**Proposition 4** The highest level of expected social welfare is given by:
- no cooperation and no investment in R&D, for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f > f_w \)
- cooperation and investment in R&D, for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : \mathcal{f}_w < f \leq f_w \)
- no cooperation and both firms investing in R&D, for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f \leq \mathcal{f}_w \)

**Proof** It follows from comparing the expected social welfare in the two subgames, described in Table 3 and Equation 14.

In Figure 3, it is possible to highlight the different social optima obtained in Proposition 4. In particular, consider the two lines \(f_w\) and \(\mathcal{f}_w\). The area between the graphs of \(f_w\) and \(\mathcal{f}_w\) represents the set of parameters \(\beta\) and \(f\) such that cooperation provides the highest level of expected social welfare. In the area above \(f_w\) the fixed cost is so high that the expected welfare is non positive and no firm invests (this private decision represents the social optimum). In the area under the line \(\mathcal{f}_w\), cooperation is not optimal and the highest welfare is achieved when both firms invest non cooperatively. With respect to the latter case, cooperation avoids duplication of fixed costs, but, at the same time, reduces the probability to obtain a new market. When the fixed cost is low enough and the spillovers high enough the second effect dominates the first, and in terms of welfare it is preferable that firms compete, both investing in R&D. In other words the gain in expected social welfare due to the increasing in the probability to obtain a new market, more than compensate the duplication of the investment.

Gathering Propositions 2 and Proposition 4, we can find the combinations of parameters \(\beta\) and \(f\) such that cooperation emerges in equilibrium and is the social optimum.

**Corollary 1** When Cooperation and investment in R&D are part of the SPNE they always provide the social optimum.

**Proof** It follows from Propositions 2 and Proposition 4.

Corollary 1 states that, when cooperation emerges in equilibrium, private decisions provide the highest level of expected social welfare. However, the reverse is not true and cooperation is not always the social optimum; hence, there is room for a public intervention: Government may boost cooperation, when necessary, providing lump-sum subsidies to firms that form an RJV and jointly invest in R&D. Public subsidies increase firms’ expected profits in the cooperative scenario, switching the equilibrium. The proposed optimal scheme of subsidies is illustrated in the following Proposition:

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18 Note that, since \(W^D > \Pi^M > 2W^D\), we have \(f_w > f_1 > f_C\), and this allows us to draw the horizontal line \(f_w\), while it is easy to show that \(\mathcal{f}_w\) is increasing in \(\beta\) and such that \(\mathcal{f}_w(\beta = 1) = \mathcal{f}_2(\beta = 1)\).
Proposition 5 The optimal lump-sum subsidy provided to firms that cooperate and invest in R&D is:

(a) \( s = 0 \) for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f > f_w\)
(b) \( s = 0 \) for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f_C \geq f > \text{MAX}[f_2; 2f_1 - f_C]\)
(c) \( s = 0 \) for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f \leq f_w\)
(d1) \( s = E\Pi^{NC}(NI; NI) - E\Pi^C(I; I) = -\rho\Pi^D + \frac{f}{2} > 0 \), for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f_w \geq f > \text{MAX}[f_1; f_C]\)
(d2) \( s = E\Pi^{NC}(I; I) - E\Pi^C(I; I) = \rho(1 - \beta)(\Pi^M - \Pi^D) - \frac{f}{2} > 0 \), for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : \text{MIN}[f_1; 2f_1 - f_C] \geq f > f_2\)
(d3) \( s = E\Pi^{NC}(I; I) - E\Pi^C(I; I) = (\rho(1 - \rho)(1 - \beta)(\Pi^M - \Pi^D) - \beta^2\Pi^D) + \frac{f}{2} > 0 \), for any \((\beta; f) \in [0, 1] \times \mathbb{R}^+ : f_2 \geq f > f_w\)

Proof (a) From Proposition 1 and Proposition 4, we obtain that the SPNE where no firm invests coincides with the social optimum. (b) It follows from Corollary 1. (c) From Proposition 3 we know that in the extended game both firms invest in equilibrium, from Proposition 4 we know that this SPNE is the social optimum. (d) In the other cases, from Proposition 3 we know that cooperation is not part of the SPNE; from Proposition 4 we know that cooperation would be the social optimum. Hence, in order to encourage cooperation we have to fix \( s > 0 \) such that \( E\Pi^C(I; I) = \text{MAX}[E\Pi^{NC}(I; I); E\Pi^{NC}(I; NI); E\Pi^{NC}(NI; NI)] \).

Figure 3 highlights areas of public intervention (scheme of subsidies).
optimum, hence subsidies would distort the private decisions leading to an inefficient allocation. In particular: in area a, the fixed cost is so high that the social optimum is achieved when firms do not invest in the market, hence any stimulus to cooperate and invest would be detrimental; in area b, cooperation spontaneously emerges in equilibrium leading to the social optimum, hence subsidies do not modify the SPNE and they would be a waste of public funds; in area c, firms do not cooperate but cooperation is not the social optimum; in area d, firms should cooperate in order to achieve the social optimum, but in equilibrium they do not; these are the values of $f$ and $\beta$ where cooperation has to be stimulated ($s > 0$).

Analyzing the optimal subsidies scheme, we obtain the following Corollary:

**Corollary 2** Optimal subsidies are decreasing (but not strictly) in $\beta$.

**Proof** Consider Proposition 5. In cases (a) (b) and (c), $s = 0$, hence $\frac{\partial s}{\partial \beta} = 0$. Otherwise, according to Proposition 1 and Proposition 3, cooperation is not part of the SPNE and we have three subcases: (d1) no firm invests; (d2) one firm invests; (d3) two firms invest. In (d1), $s = -\rho \Pi^D + \frac{f}{2}$, we have $\frac{\partial s}{\partial \beta} = 0$; in (d2), $s = \rho (1 - \beta) (\Pi^M - \Pi^D) - \frac{f}{2}$, we have $\frac{\partial s}{\partial \beta} = -\rho (\Pi^M - \Pi^D) \leq 0$; in (d3), $s = (\rho (1 - \beta) (\Pi^M - \Pi^D) - \beta \rho^2 \Pi^D) + \frac{f}{2}$; we have $\frac{\partial s}{\partial \beta} = -\rho (1 - \rho) (\Pi^M - \Pi^D) + \rho \Pi^D \leq 0$.

The intuition behind Corollary 2 is that, while the cooperative expected profit is constant (spillovers are internalized), non cooperative ones are decreasing in $\beta$; hence, in order to shift the equilibrium from non cooperation to cooperation, the subsidies should be higher when spillovers are lower. The implication is that Government should subsidize heavily the R&D cooperation in markets with lower spillovers, that, for example, are the one with high effective patent protection, that restrain imitation and spillovers.  

Summing up, our analysis provides some relevant results on the role of cooperation. Forming a RJV is not always the social optimum; as a consequence, subsidizing always R&D cooperation may not be the optimal policy. We show that, when it emerges in equilibrium of the game, cooperation is efficient, hence subsidies would be a waste of public funds; however there are cases where cooperation is efficient but does not emerge (subsidies are necessary) and cases where cooperation is not efficient and does not emerge (subsidy are not necessary). Finally, when cooperation is efficient but does not emerge spontaneously, subsidies should be designed according to the level of fixed costs and spillovers: as proved in Corollary 2, the lower the spillovers, the higher the subsidies required.  

### 4 Cooperation and collusion

Consider now a modified game where cooperation in R&D leads always to collusion in the market stage. In the following, we use the index CC to label this cooperative-collusive case. The expected profit of the subgame becomes:

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19 Note that this result partially contradict Hinloopen (1997), where optimal subsides are increasing in the spillover rate; however he considers subsides to R&D investment and not to R&D cooperation.

20 Miyagiwa (2009) states: "Prior to the 1960’s the suspicion (that cooperation in R&D among firms producing similar products leads to product market collusion) was so strong in the U.S. that antitrust authorities threatened to punish any form of research joint ventures with the full force of antitrust laws. (...) Although today joint research activities are encouraged everywhere, the same old suspicion lingers: does cooperation in R&D facilitate product market collusion?" (pg. 768).
\[ EI_i^{CC}(I; I) = \beta \frac{M}{2} - \frac{f}{2} \]  

We denote by \( f^{CC} \) the private incentive to coagulate-monopolist profit such that the expected profit of firm \( i \) is not negative \( (EI_i^{CC}(I; I) \geq 0, \text{participation constraint}) \) and non lower than her expected profit when the RJV does not invest \( (EI_i^{CC}(I; I) \geq EI_i^{CC}(NI; NI), \text{incentive compatibility constraint}) \). In this case \( EI_i^{CC}(NI; NI) = 0 \), hence the two constraints coincide; we obtain:

\[ f^{CC} = \rho M \]  

By comparison, it is easy to check that \( f^{CC} \geq f_1 \). Using equation 19, we can write the expected profit of firm \( i \) expressed in equation 18 as a function of \( f^{CC} \), obtaining:

\[ EI_i^{CC}(I; I) = \frac{f^{CC}}{2} - \frac{f}{2} \]  

Definition 19 leads us to the following proposition:

**Proposition 6** At \( t = 0 \), cooperation and collusion is part of the SPNE of the modified game for any \((\beta; f) \in [0,1] \times \mathbb{R}^+ : f^{CC} \geq f > \max[f_2; 2f_1 - f^{CC}]\) or any \((\beta; f) \in [0,1] \times \mathbb{R}^+ : f_2 \geq f \geq 2f_2 + \beta f_c - f^{CC}\).

Proof - If \( f > f^{CC} > f_1 \) we have \( EI_i^{NC}(I; NI) < 0 \) and \( EI_i^{CC}(I; I) < 0 \); then, since \( EI_i^{NC}(NI; NI) = 0 \), at \( t = 0 \) firms do not cooperate and at \( t = 1 \) they do not invest.

- If \( f > f_1 > f_2 \text{ and } f \leq f^{CC} \), we have \( EI_i^{CC}(I; I) \geq 0 > EI_i^{NC}(I; I) \) then, at \( t = 0 \) firms cooperate and at \( t = 1 \) both invest.

- If \( f_1 \geq f > f_2 \), we have \( EI_i^{NC}(I; NI) \geq 0 \) and \( EI_i^{CC}(I; I) \geq 0 \); then, at \( t = 0 \) firms cooperate if and only if \( EI_i^{CC}(I; I) \geq EI_i^{NC}(I; NI) \); using equations 6 and 20 this is true if and only if \( \frac{f^{CC}}{2} - \frac{f}{2} > f_1 - f \), that is \( f \geq 2f_1 - f^{CC} \).

- If \( f \leq f_2 \), we have \( EI_i^{NC}(I; I) \geq 0 \) and \( EI_i^{CC}(I; I) \geq 0 \); then, at \( t = 0 \) firms cooperate if and only if \( EI_i^{NC}(I; I) \geq EI_i^{NC}(I; NI) \); using equations 8 and 20 this is true if and only if \( \frac{f^{CC}}{2} - \frac{f}{2} \geq f_2 + \rho \beta M - f \), that is \( f \geq 2f_2 + 2\rho \beta M - \rho M = 2f_2 + \beta f_c - f^{CC} \).

Proposition 6 implies that collusion enlarges the parameter set \( \beta \) and \( f \) such that cooperation emerges in equilibrium, this is due to the increased cooperative expected profits.

Since cooperating firms share the monopolistic profit, the expected social welfare is:

\[ EW^{CC}(I; I) = \rho M - f \]  

Defining \( f^{CC}_w \) the level of fixed cost such that \( EW^{CC}(I; I) = 0 \), we have:

\[ f^{CC}_w = \rho M \]  

Comparing expected social welfare in case of cooperation with the one where only one firm invests, it is easy to show that the latter is always bigger than the
former \((EW^{NC}(I;NI) \geq EW^{CC}(I;I))\). Comparing expected social welfare in case of cooperation with the one where both firms invest non cooperatively, we have that \(EW^{CC}(I;I) \geq EW^{NC}(I;I)\) if and only if the fixed cost is high enough, i.e. \(f \geq f^{CC} = \rho(W^D - W^M(2\beta(1-\rho) + \rho) + W^M(1-\rho))\); however it is possible to show that \(f^{CC} > f^{CC}\), hence \(f \geq f^{CC}\) is satisfied only for a negative level of expected social welfare. Finally, when \(f_1 < f \leq f^{CC}\) the equilibrium of the non cooperative subgame leads no firm to invest while cooperation provides expected positive social welfare; however also in this case, even thought cooperation emerges in equilibrium, the level of welfare would be higher when only one firm invests.

We can summarize the previous analysis in the following Corollaries:

**Corollary 3** Collusion enlarges the parameter set where firms invest in R&D.

*Proof* It follows from comparing Propositions 3 and 6.

**Corollary 4** With collusion, when cooperation and investment in R&D are part of the SPNE they never provide the social optimum.

*Proof* It follows from comparing the expected social welfare in the two subgames, described in Table 3 and Equation 21.

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**Fig. 4** Cooperation as SPNE of the modified game.
In Figure 4 we highlight the three areas where collusion makes firms cooperate in equilibrium. Area CC1 is the set of parameters where firms cooperate even without collusion; area CC2 is the set of parameters where without collusion firms do not cooperate but at least one invests in equilibrium; area CC3 is the set of parameters where without collusion firms do not cooperate and none invests in equilibrium.

With collusion, cooperation does not maximizes the social welfare; nevertheless, collusion enlarges the parameter set where firms invest in R&D, increasing the dynamic efficiency of the market: if \( \max[f_1, f_C] < f < f^{CC} \) (in area CC3 of Figure 4), cooperation emerges in equilibrium only when collusion is sustainable: in a case where, without collusion, firms would not invest, collusion increases expected returns making R&D investment profitable. In other words, in area CC3, without collusion, Government should boost firms to cooperate and invest through the incentive scheme proposed in Proposition 5. Unfortunately, when subsidies are costly, subsidizing firms is not a zero-sum transfer but reduces expected social welfare. As a consequence, cooperate and collude may represent a second best outcome, for a shadow cost of public funds high enough.

Hereafter, we assume that public subsidies are costly to taxpayers, distorting the economy, i.e. any euro transferred to firms costs to the economy \( 1 + \lambda \), where \( \lambda > 0 \) is the shadow cost of public funds. Focusing on the parameters set defined by Corollary 3, we can compare cooperation-collusion with cooperation with costly subsidies. We find out under which conditions the former scenario is preferable to the latter in terms of expected social welfare:

**Proposition 7** When \( \max[f_1, f_C] < f < f^{CC} \), cooperation-collusion is preferable to cooperation with costly subsidies if and only if the shadow cost of public funds is higher than the threshold value \( \lambda(s) = \frac{\rho (W^D - W^M)}{s} \), where \( s = \frac{f}{2} - \rho h^D \).

**Proof** Without collusion cooperation does not emerge as equilibrium in the set of parameters \( \beta \) and \( f \) described in case (d) of Proposition 5. In such subset, we have that \( EW^{CC}(I; I) > EW^C(I; I) - \lambda s \) if and only if \( \lambda > \lambda(s) = \frac{\rho (W^D - W^M)}{f/2 - \rho h^D} \).

Proposition 7 states that when the subsidy \( s \) required to cooperate is high, the probability to innovate \( \rho \) is low, the difference between welfare in duopolistic and monopolistic markets \( W^D - W^M \) is low, cooperation-collusion may be a second best solution. The latter condition may occur, for example, when goods are highly differentiated, demand is inelastic or firms compete in geographically separated market.

When \( \lambda \) is high enough, tolerating collusion gives firms higher incentives to invest in R&D providing higher dynamic efficiency to the markets. The same argument can be referred to mergers or acquisitions in innovative markets that, if on the one hand increase market concentration, on the other hand boost R&D returns appropriability and private incentives to invest in R&D as well.

5 Conclusions

In our paper, we have analyzed a non-tournament competition for a stochastic product innovation in a three stage game, where cooperation may endogenously emerge in equilibrium.

Our paper have extended the results of the theoretical literature introducing several elements of novelty: (i) we have focused on stochastic product innovation; (ii) we have assumed that cooperation is the result of strategic decisions; (iii) we have
proposed an optimal subsidy scheme to boost cooperation; and (iv) we have studied the impact in terms of welfare of collusion when subsidies are costly to taxpayers and there exists a (positive) shadow cost of public funds.

In the theoretical framework described in our paper, cooperation is socially efficient when spontaneously emerges in equilibrium; nevertheless, it is not always the social optimum. Consequently, boosting R&D cooperation is not necessary in some cases (i.e. when firms spontaneously cooperate), in others it may be detrimental (i.e. when the social optimum required competition in R&D activities or when the fixed cost is too high). In industries with low spillovers firms tend to compete in R&D rather than to cooperate, even though cooperation should be the social optimum, hence there is room for public intervention. In order to stimulate R&D cooperation in these industries, Government should use some tangible incentive, as, for example, subsidies which, as we proved, have to be decreasing in the levels of spillovers. In other words, subsidies have to be higher in R&D intensive industries (e.g. biotechnology and pharmaceutical, aircraft and spacecraft, etc.) generally characterized by high effective patent protection, that is detrimental to spillovers. Notice that product innovations are usually covered by a huge number of patents, which may negatively affect spillovers. On the contrary, cooperation may emerge in equilibrium in industries with high spillovers; in this case, subsidies are not necessary and Government should use less regulation and intervention, and lets market achieve the spontaneous equilibrium. Thus, in order to boost investment through R&D cooperation, Government should investigate the correct magnitude of spillovers, and differentiate incentives according to industries characteristics. Unfortunately, most public policies to boost innovation, as for example the European Framework Programme, do not seem to consider this criterium to allocate funds.

Moreover, we have showed that cooperation is always efficient when spontaneously emerges in equilibrium; however, cooperation is not always the social optimum. Consequently, boosting R&D cooperation in some cases is not necessary (i.e. when firms spontaneously cooperate); in other cases it may be detrimental (i.e. when the social optimum required competition in R&D activities) or too expensive (i.e. when the fixed cost is too high). Subsidies to cooperation in R&D increase efficiency in private decisions of investment only for intermediate values of fixed costs.

Finally, we have analyzed the case of collusion in the market stage. Collusion increases the private incentive to invest and cooperate in R&D, reducing the cases where firms need public subsidies. Even though cooperation and collusion never provides the highest level of expected social welfare, in this alternative scenario firms invest in R&D for combinations of the parameters so that without subsidies firms would not invest at all. In this cases, tolerating collusion can be alternative to subsidizing firms, in order to boost investment in R&D. When subsidies are costly to the taxpayers, collusion may lead to a social welfare improvement and may represent a sort of second best solution. The same argument can be referred to mergers or acquisitions in innovative markets that, if on the one hand increase market concentration, on the other hand increase R&D returns appropriability and private incentives to invest in R&D.
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