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

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Abstract

The paper analyzes the impact of post-innovation knowledge spillovers on private firms' R&D investment decisions, considering the case of stochastic product innovation. We propose a theoretical model where we compare two scenarios: not cooperation in R&D versus Research Joint Ventures (RJV); our analysis extends the results of the literature to the context of product innovation, confirming the general result that the presence of spillovers reduces private incentive to invest and may stimulate cooperation. Moreover, in terms of social welfare, our analysis suggests that cooperation may not be optimal and, as a consequence, subsidizing any form of R&D cooperation is not efficient. We show that cooperation in R&D leads always to the efficient allocation; however there are cases where cooperating emerges spontaneously as SPNE, and cases where cooperating does not emerge without subsides. Finally, when we assume that cooperating firms collude in the production stage, the increasing of the private incentive to cooperate reduces the cases where firms need public subsides to invest: when subsidies are costly, cooperation-collusion may be a second best solution.

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1 Introduction

During the last decades, Economic literature has deeply analyzed the causes and the effects of R&D cooperation, showing how, why and with who firms cooperate. Given the large number of firms involved in R&D projects all over the world, many data are available and R&D cooperation has been the subject of a huge amount of empirical articles; with respect to this growing literature dealing, *inter alia*, with the determinants of cooperation, or the choice of partners, or the effect of public policies, etc. there is a lack of theoretical contributions.[1] Our paper wish to contribute to this second, more scarce, literature.

The large majority of theoretical models dealing with R&D cooperation and spillovers, assume oligopolistic firms playing a two stage game: at the first stage firms choose R&D levels cooperatively or non-cooperatively and at the second stage they play price or quantity competition. The seminal contribution is d'Aspremont and Jacquemin (1988), where authors, comparing three different scenarios in case of 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 substantial spillovers, cooperative R&D leads to higher profits and social welfare. Kamien et al. (1992) introduce in the analysis product differentiation. 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 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.

A significant proportion of contributions tries to incorporate in the analysis the impact of spillovers in R&D process innovation: knowledge (or incoming) spillovers are positive production externalities reducing costs for all the firm in the market. In case of product innovation, incoming spillovers allow firms that did not innovate to imitate the new good and compete in the market, obtaining costless advantages from competi-

[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 contributions by d'Aspremont and Jacquemin (1988) and Kamien et al. (1992); other papers on this topic are Martin (1995), Cabral (2000), Lambertini et al. (2003), Cabon-Dhersin (2008), Miyagiwa (2009), Yao and Zheng (2014). Goere and Helland (2009) prove empirically that stricter antitrust rules on R&D cooperation may reduce the probability that firms will create RJVs, implying that some RJVs are formed for anti-competitive purposes.

tors' R&D activities. Spillovers, that are a sort of external knowledge flows, reduce R&D returns appropriability and induce firms to underinvest with respect to the social optimum; hence there is room for State interventions using, for example, subsides to R&D.[3]

In this paper, we analyze the impact of post-innovation knowledge spillovers on private firms decisions to invest in R&D and to form a Research Joint Venture (RJV),[4] considering the case of product innovation in markets where imitation is possible.[5]

Our paper contributes to the theoretical literature in several ways: first, while all the theoretical literature compares two scenarios (not cooperation in R&D versus cooperation) in a two stages game, to the best of our knowledge, we are the first to propose a model where the choice to cooperate is not exogenously given and may emerge as equilibrium of a three stages game; second, while most of the literature analyzes the case of marginal cost-reducing innovation, we focus on stochastic product innovation with spillovers; third, we show the cases where R&D cooperation is efficient and propose an optimal scheme of subsides: despite many authors affirm the necessity of a public intervention, few of them try to provide such a scheme;[6] finally, we consider how our results

[3]The empirical literature has analyzed the role of public policies on the innovation behavior of the firms. One of the main question regards the crowding-out effect caused by subsides: public funds may crowd out private ones, financing research projects which would have been undertaken even without government support. However, recent literature does not find clear evidence of the crowding out effect (see, inter alia, Busom, 2000; Wallsten, 2000; Lach ,2002; Czarnitzki and Fier, 2002; Almus and Czarnitzki, 2003; Gonzalez et al., 2005; a meta regression analysis of this literature is Dimos and Pugh, 2014). On the contrary, a well-known result states that, when spill-overs are high enough, cooperating in R&D will bring higher investment compared to the status of no collaboration (see, inter alia, De Bondt and Veugelers, 1991) and always increase firms' profitability, enhancing social welfare. Hence, if subsidization of R&D cooperation increases such a cooperation, stimulating it may be a better way to use public funds, compared to direct subsidies to R&D.

[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).

[5]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.

[6]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.

change, in case firms use R&D cooperation to collude at the market stage.

Our analysis extends the results of the literature to the context of product innovation: the presence of spillovers reduces private incentive to invest and stimulates cooperation. In particular, firms collaborate in R&D when the spillover is high enough and the associated cost is low enough. In terms of welfare, cooperation may not be the social optimum because, if on the one hand firms reduce the investment risk sharing the costs, 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 any form of R&D cooperation is not the social optimum: our analysis suggests cases where cooperation is efficient and emerges spontaneously as SPNE (subsides are a waste of public funds) and, cases where cooperation is efficient but does not emerges (subsides are necessary). In general the optimal subsides scheme should be designed according to the intensity of spillovers, the level of R&D costs and the probability to succeeding in innovation. Introducing collusion in the market stage increases the private incentive to invest and cooperate in R&D, reducing the cases where firms need public subsides. In cases of costly subsides, this may lead to a social welfare improvement, and tolerate collusion may be preferable to subside R&D cooperation.

The paper is organized as follows: in Section 2 we present the model and analyze the subgame perfect Nash equilibrium (SPNE) of the game, focusing on the case where cooperation in R&D emerges as an 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),[7] we consider the case of $n = 2$ firms, i and j, as potential investors in a non-tournament stochastic product R&D process:[8] each firm decides whether

[7]See pages 490-492.

[8]R&D literature distinguishes between tournament and non-tournament models. In tournament models the first competitor that succeeds in innovating ends up to be the only innovator which mostly comes down to winning a (patent) race. The model can be stochastic or deterministic but what is essential is that the winner takes all and becomes the monopolistic firm in the market of the new product. Conversely, in non-tournament model competitors are not engaged in a race, there is not a winner but all players can succeed and innovate. For a survey on R&D literature see Marinucci

to bear or not a fixed cost $f > 0$, in order to produce an innovative good with probability $\rho \in [0, 1]$.[9] We assume that 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.

When innovation occurs, if one firm can produce the new good, she plays monopoly, otherwise firms play duopoly. 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 Π^M and Π^D the monopoly and duopoly profits before fixed costs f (where $\Pi^M \geq 2\Pi^D$),[10] 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 $W^D < 2W^M$).[11]

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 the 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.

(2012).

[9]The probability of success associated to the fixed cost f is exogenous, equal for both firms and independent on the number of competing investors.

[10]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.

[11]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.

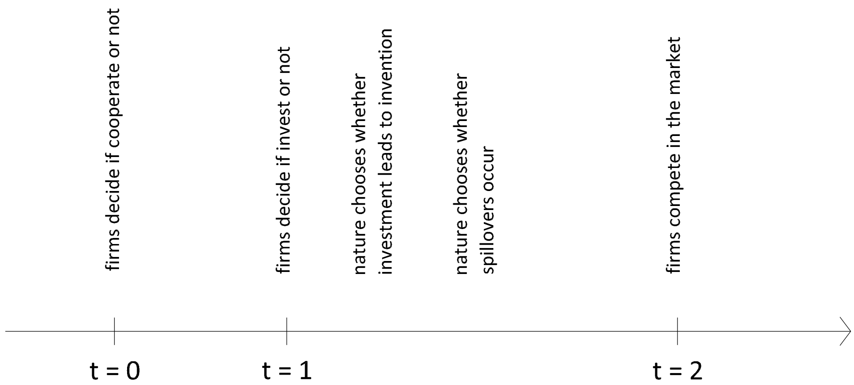

Figure 1: The timing of the game

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 ρ firm i innovates. In such a case: with probability ρ firm j innovates as well, firms share the market achieving duopolistic profit Π^D. With probability $1-\rho$ firm j does not innovate. In this subcase: with probability β spillovers allow firm j to imitate the new good and enter the market achieving the duopolistic profit Π^D; otherwise, with probability $1-\beta$ firm i is the only one producing the new good obtaining the monopolistic profit Π^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 ρ firm j innovates. In this subcase: with probability β spillovers allow firm i to imitate the new good and enter the market achieving the duopolistic profit Π^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 Π^D when both firms innovate (with probability ρ^2) or one innovates and the other imitates (with probability $2(1-\rho)\beta$); firm i obtains the monopolistic profit Π^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:

$$E\Pi_i^{NC}(I;I) = \rho[\rho + 2(1-\rho)\beta]\Pi^D + \rho(1-\rho)(1-\beta)\Pi^M - f \tag{1}$$

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

$$E\Pi_i^{NC}(NI;I) = \rho\beta\Pi^D \tag{2}$$

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

$$E\Pi_i^{NC}(I;NI) = \rho[\beta\Pi^D + (1-\beta)\Pi^M] - f \tag{3}$$

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

$$E\Pi_i^{NC}(NI;NI) = 0 \tag{4}$$

Table 1 summarizes these results.

Table 1: Firm i expected profits, in the four possible non-cooperative outcomes

	I	NI
I	$\rho[\rho + 2(1-\rho)\beta]\pi^D +$ $\rho(1-\rho)(1-\beta)\pi^M - f$	$\rho[\beta\pi^D + (1-\beta)\pi^M] - f$
NI	$\rho\beta\pi^D$	0

In order to obtain the equilibrium of the non-cooperative subgame, we compute the per-firm incentives to innovate; it is the threshold levels of the fixed cost f that, in equilibrium, makes the 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 ($E\Pi_i^{NC}(I;NI) \geq 0$, participation constraint) and non-lower than her expected profit when she does not invest ($E\Pi_i^{NC}(I;NI) \geq E\Pi_i^{NC}(NI;NI)$, incentive compatibility constraint). Since not investing firm i obtains expected profit equal to zero, both constraints are binding; we obtain:

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

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

$$E\Pi_i^{NC}(I;NI) = f_1 - f \tag{6}$$

Analogously, assume 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 ($E\Pi_i^{NC}(I;I) \geq 0$, participation constraint) and non lower than her expected profit when she does not invest ($E\Pi_i^{NC}(I;I) \geq E\Pi_i^{NC}(NI;I)$, 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:

$$f_2 = \rho\Pi^M - \rho^2\left(\Pi^M - \Pi^D\right) - \beta\left(\rho(1-\rho)\left(\Pi^M - 2\Pi^D\right) + \rho\Pi^D\right) \tag{7}$$

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

$$E\Pi_i^{NC}(I;I) = f_2 + \rho\beta\Pi^D - f \tag{8}$$

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):

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

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:

$$\begin{aligned} f_2 &= f_2|_{\beta=0} - \beta\left(\rho(1-\rho)\left(\Pi^M - 2\Pi^D\right) + \rho\Pi^D\right) \\ \frac{\partial f_2}{\partial \beta} &= -\left(\rho(1-\rho)\left(\Pi^M - 2\Pi^D\right) + \rho\Pi^D\right) < 0 \end{aligned}$$

and

$$f_1 = f_1|_{\beta=0} - \rho\beta(\Pi^M - \Pi^D)$$
$$\frac{\partial f_1}{\partial \beta} = -\rho\beta(\Pi^M - \Pi^D) < 0$$

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

Proof.

- Suppose firm j does not invest in R&D, firm i does not invest in R&D as well, if and only if $E\Pi_i^{NC}(NI; NI) \geq E\Pi_i^{NC}(I; NI)$, that is $E\Pi_i^{NC}(I; NI) \leq 0$; 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 $E\Pi_i^{NC}(I; NI) \geq E\Pi_i^{NC}(NI; NI)$, that is $E\Pi_i^{NC}(I; NI) \geq 0$, 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 $E\Pi_j^{NC}(NI; I) \geq E\Pi_j^{NC}(I; I)$, using equations 2 and 8 this is true if and only if $\rho\beta\Pi^D \geq f_2 + \rho\beta\Pi^D - f$, 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 $E\Pi_i^{NC}(I; I) \geq E\Pi_i^{NC}(NI; I)$, using equations 2 and 8 this is true if and only if $f_2 + \rho\beta\Pi^D - f \geq \rho\beta\Pi^D$, i.e. $f \leq f_2$.

■

Proposition 1 states that the choice to invest in R&D depends on the fixed cost: 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.[12]

[12]When $f_1 \geq f > f_2$ we have two vectors as part of the SPNE in pure strategies, $(I; NI)$ or $(NI; I)$. As a consequence the non-cooperative subgame admits an equilibrium in mixed strategies whose simple characterization is outside the scope of this work.

2.3 The cooperative subgame

In the cooperative subgame there are only two possible outcomes: both firms invest in R&D $(I; I)$, no firm invests $(NI; NI)$.

If firms form a RJV, they share the R&D cost. In case of innovation, they internalize the spillovers jointly patenting any new good, and they compete in duopoly in the final stage. Hence, the expected profit of firm i is the following:

$$E\Pi_i^C(I; I) = \rho\Pi^D - \frac{f}{2} \tag{10}$$

If firms do not invest in R&D, they obtain zero profits:

$$E\Pi_i^C(NI; NI) = 0 \tag{11}$$

Table 2 illustrates these results.

Table 2: Firm i expected profits, in the two possible cooperative cases

	I	NI
I	$\rho\pi^D - \frac{f}{2}$	$\blacksquare$
NI	$\blacksquare$	0

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 ($E\Pi_i^C(I; I) \geq 0$).[13] Hence, from (10) we have:

$$f_C = 2\rho\Pi^D \tag{12}$$

Note that f_C does not depend on β, since spillovers are internalized.

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

$$E\Pi_i^C(I; I) = \frac{f_C}{2} - \frac{f}{2} \tag{13}$$

Using equation 12, we can state the following Proposition:

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

[13] 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. Here, firms have two alternatives: to invest jointly or not to invest at all. In the second case the expected profits are zero.

Proof. It follows from the non negativity condition on the expected profit $E\Pi_C$. ■

Proposition 2 asserts that, in this 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 two SPNE of the alternative subgames (i.e. the non-cooperative and the cooperative ones). When firms cooperate they form a RJV and sign a full-commitment agreement, excluding any sort of free-riding or opportunistic behavior. 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 $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f_C \geq f > \max[f_2; 2f_1 - f_C] \cup$ any $(\beta; f) \in [0,1] \times \mathbb{R}^+ : \min[f_2; f_C] \geq f \geq 2f_2 - (1-\beta)f_C$.*

Proof.

- If $f > f_1$ and $f > f_C$, we have $E\Pi_i^{NC}(I; I) < 0$ and $E\Pi_i^C(I; I) < 0$; then, at $t = 0$ firms do not cooperate and at $t = 1$ they do not invest.
- If $f > f_1$ and $f \leq f_C$, we have $E\Pi_i^C(I; I) \geq 0 > E\Pi_i^{NC}(I; I)$; then, at $t = 0$ firms cooperate and at $t = 1$ both invest.
- If $f_1 \geq f > f_2$ and $f > f_C$, we have $E\Pi_i^{NC}(I; NI) \geq 0 > E\Pi_i^C(I; I)$; then, at $t = 0$ firms do not cooperate and at $t = 1$ only one does invest.
- If $f_1 \geq f > f_2$ and $f \leq f_C$, we have $E\Pi_i^{NC}(I; NI) \geq 0$ and $E\Pi_i^C(I; I) \geq 0$; then, at $t = 0$ firms cooperate if and only if $E\Pi_i^C(I; I) \geq E\Pi_i^{NC}(I; NI)$; using equations 6 and 13 this is true if and only if $\frac{f_C}{2} - \frac{f}{2} \geq f_1 - f$, that is $f \geq 2f_1 - f_C$.
- If $f \leq f_2$ and $f > f_C$, we have $E\Pi_i^{NC}(I; I) \geq 0 > E\Pi_i^C(I; I)$; then, at $t = 0$ firms do not cooperate and at $t = 1$ both invest.
- if $f \leq f_2$ and $f \leq f_C$, we have $E\Pi_i^{NC}(I; I) \geq 0$ and $E\Pi_i^C(I; I) \geq 0$; then, at $t = 0$ firms cooperate if and only if $E\Pi_i^C(I; I) \geq E\Pi_i^{NC}(I; I)$; using equations 8 and 13 this is true if and only

if $\frac{f_C}{2} - \frac{f}{2} \geq f_2 + \rho\beta\Pi^D - f$, that is $f \geq 2f_2 - (1-\beta)f_C$; if $\rho \leq \tilde{\rho} = \frac{\Pi^M - 2\Pi^D}{\Pi^M - \Pi^D}$ 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 equilibria, then, at $t = 0$ firms cooperate and at $t = 1$ both invest if and only if $f \in \mathbb{R}^+ : f \leq f_C$ and $f \leq f_2$ and $f \geq 2f_2 - (1-\beta)f_C$.

■

Proposition 3 describes the combinations of parameters β and f where cooperation emerges as part of the equilibrium of the extended game. We have this result for high levels of β 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 monopoistic profit (achievable only without cooperation) is larger than the saving due to the sharing of the fixed cost obtained by cooperation; for intermediate values of f, the latter effect may dominate the former: in this case 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 evaluations of R&D

The aim of this Section is ranking the different outcomes of the 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. It depends on the equilibria investment decisions, the spillovers parameter β, the probability of success ρ associated to investment in R&D and the level of welfare in duopoly W^D and monopoly W^M, at time $t = 2$.

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

Consider now the cooperative subgame; in this case the expected social welfare is given by:

$$EW^C(I; I) = \rho W^D - f \tag{14}$$

The public value of cooperation f_w is given by the maximum level of fixed cost f such that the expected welfare of cooperation is non-negative. Hence, we have:

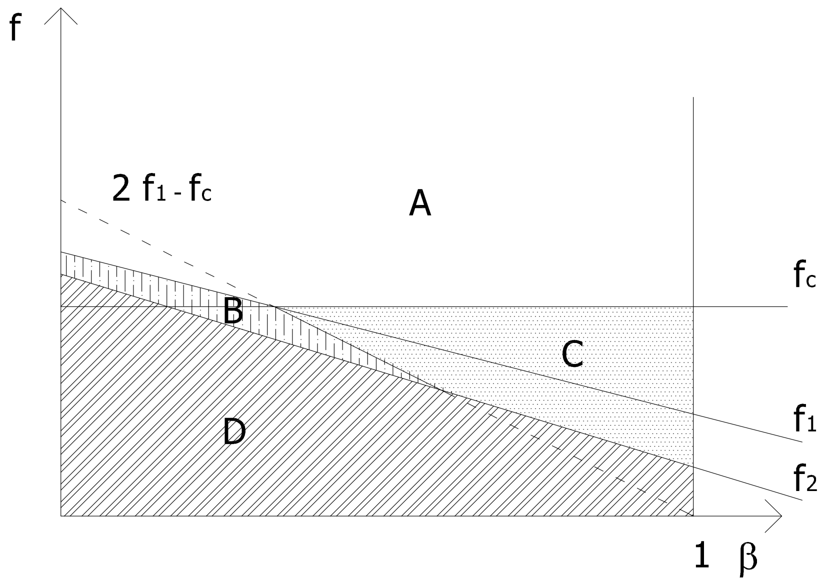

Figure 2: The SPNE of the extended game.

$$f_w = \rho W^D \tag{15}$$

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), cooperating firms halve the per-firm cost of investing in R&D and the research lines. As a consequence this reduces the probability to innovate with respect to the case where both firms invest in $R\&D$ ($\rho(2-\rho) > \rho$), and makes zero the probability to have a monopoly in the market. Hence, it may be the case that, for levels of β high enough and levels of f low enough, $EW^{NC}(I;I) \geq EW^{C}(I;I)$: we

Table 3: The expected social welfare

	I	NI
I	$\rho\left(\rho W^D + 2(1-\rho)\beta W^D + 2(1-\rho)(1-\beta)W^M\right) - 2f$	$\rho\left(\beta W^D + (1-\beta)W^M\right) - f$
NI	$\rho\left(\beta W^D + (1-\beta)W^M\right) - f$	0

define $\overline{f}_w$ the threshold value of the fixed cost f such that $EW^{NC}(I;I) = EW^{C}(I;I)$. We have:

$$\overline{f}_w = \rho(1-\rho)[W^D - 2(1-\beta)(W^D - W^M)] \tag{16}$$

Using equations 15 and 16, 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 $(\beta; f) \in [0,1] \times \mathbb{R}^+ : \overline{f}_w < f \leq f_w$
- no cooperation and both firms investing in R&D, for any $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f \leq \overline{f}_w$

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. In particular, consider the two lines f_w and $\overline{f}_w$.[14] The area between the graphs of f_w and $\overline{f}_w$ represents he set of parameters 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 $\overline{f}_w$, cooperation is not optimal and the highest welfare is achieved when both the firms invest non cooperatively: if the firms cooperate the probability to obtain a new market decreases, in this case the fixed cost is low enough that the social optimum is given by both firms investing in R&D, in other words the gain in probability and the high spillovers more than compensate the duplication of the investment.

Gathering Propositions 2 and Proposition 4, we can find the combinations of parameters where cooperation emerges in equilibrium and it is the social optimum. This leads to Corollary 1:

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 spontaneously as equilibrium, private decisions provide the highest level of expected social

[14] Note that, since $W^D > \Pi^M > 2\Pi^D$, we have $f_w > f_1 \geq f_C$, and this allows us to draw the horizontal line f_w, while it is easy to show that $\overline{f}_w$ is increasing in β and such that $\overline{f}_w(\beta = 1) = f_2(\beta = 1)$.

welfare. However, the reverse is not true; hence, there is room for a public intervention as illustrated in Proposition 5:

Proposition 5 *Optimal subsidies are:*

(a) $s = 0$ *for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f > f_w$

(b) $s = 0$ *for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f_C \geq f > MAX\,[f_2; 2f_1 - f_C]$

(c) $s = 0$ *for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f \leq \overline{f}_w$

(d₁) $s = E\Pi^{NC}(NI; NI) - E\Pi^{C}(I; I) = -\rho\Pi^D + \frac{f}{2} > 0$*, for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f_w \geq f > \max[f_1; f_C]$

(d₂) $s = E\Pi^{NC}(I; NI) - E\Pi^{C}(I; I) = \rho(1-\beta)\left(\Pi^M - \Pi^D\right) - \frac{f}{2} > 0$*, for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : \min[f_1; 2f_1 - f_C] \geq f > f_2$

(d₃) $s = E\Pi^{NC}(I; I) - E\Pi^{C}(I; I) = (\rho(1-\rho)(1-\beta)(\Pi^M - \Pi^D) - \beta\rho^2\Pi^D) + \frac{f}{2} > 0$*, for any* $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f_2 \geq f > \overline{f}_w$

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 $E\Pi^C(I; I) = MAX[E\Pi^{NC}(I; I); E\Pi^{NC}(I; NI); E\Pi^{NC}(NI; NI)]$. ■

Figure 3 highlights areas of public intervention. Following Proposition 5,we draw four main regions. In areas a, b and c the equilibrium of the game leads to the social optimum, hence subsides 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 cooperation and investments would be detrimental; in area b, cooperation spontaneously emerges at the equilibrium leading to the social optimum, hence subsides do not modify the SPNE and they would be a waste of 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 β where cooperation has to be stimulated ($s > 0$).

Analyzing the optimal subsidies, we obtain the following Corollary:

Corollary 2 *Optimal subsidies are decreasing (but not strictly) in* β*.*

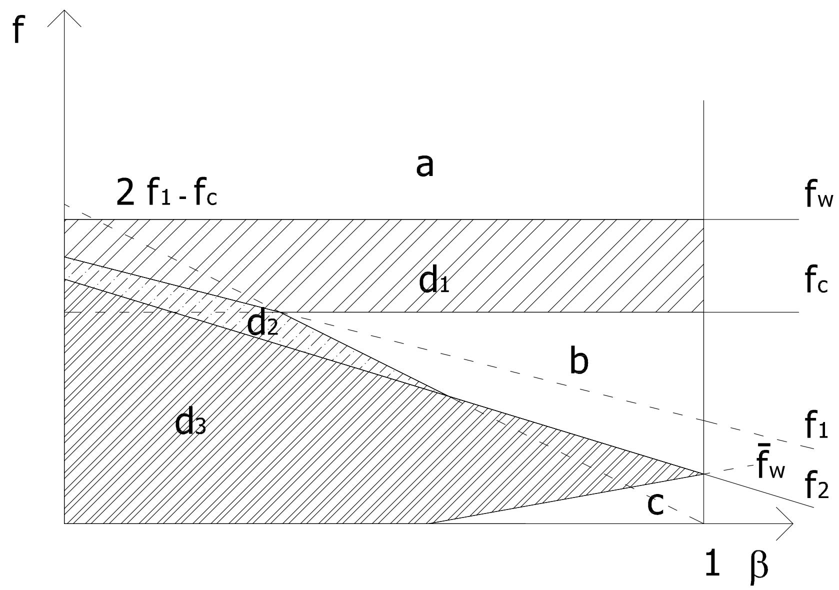

Figure 3: Areas of public intervention (scheme of subsidies).

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), $s = \rho(1-\beta)\left(\Pi^M - \Pi^D\right) - \frac{f}{2}$, we have $\frac{\partial s}{\partial \beta} = -\rho(\Pi^M - \Pi^D) \leq 0$; in (d3), $s = \left(\rho(1-\rho)(1-\beta)\left(\Pi^M - \Pi^D\right) - \beta\rho^2\Pi^D\right) + \frac{f}{2}$; we have $\frac{\partial s}{\partial \beta} = -\rho[(1-\rho)(\Pi^M - \Pi^D) + \rho \Pi^D] \leq 0$. ■

Summing up, our analysis provides some relevant results on the role of cooperation. Contrary to most of the literature on R&D and spillovers, in our model cooperation is not always socially preferable. It follows that subsidizing firms that cooperate may not be efficient. Finally, even in cases where 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 cooperating in R&D leads always to collusion in the market stage.[15] In the following, we use the index CC to label this cooperative-collusive case. The expected profit of the subgame becomes:

$$E\Pi_i^{CC}(I;I) = \rho\frac{\Pi^M}{2} - \frac{f}{2} \tag{17}$$

Assume collusion is sustainable. We denote by f^{CC} the private incentive to cooperate-collude, given by the maximum level of the fixed cost f such that the expected profit of firm i is not negative ($E\Pi_i^{CC}(I;I) \geq 0$, participation constraint) and non lower than her expected profit when she does not invest ($E\Pi_i^{CC}(I;I) \geq E\Pi_i^{CC}(NI;NI)$ incentive compatibility constraint). In this case $E\Pi_i^{CC}(NI;NI) = 0$, hence the two constraints coincide; we obtain:

$$f^{CC} = \rho\Pi^M \tag{18}$$

By comparison, it is easy to check that $f^{CC} \geq f_1$. Using equation 18, we can write the expected profit of firm i expressed in equation 17 as a function of f^{CC}, obtaining:

$$E\Pi_i^{CC}(I;I) = \frac{f^{CC}}{2} - \frac{f}{2} \tag{19}$$

Definition 18 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 $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f^{CC} \geq f > \max[f_2; 2f_1 - f^{CC}] \cup$ any $(\beta; f) \in [0,1] \times \mathbb{R}^+ : f_2 \geq f \geq 2f_2 + \beta f_C - f^{CC}$.*

Proof.

- If $f > f^{CC}$ we have $E\Pi_i^{NC}(I;I) < 0$ and $E\Pi_i^{CC}(I;I) < 0$; then, at $t = 0$ firms do not cooperate and at $t = 1$ they do not invest.
- If $f > f_1$ and $f \leq f^{CC}$, we have $E\Pi_i^{CC}(I;I) \geq 0 > E\Pi_i^{NC}(I;I)$; then, at $t = 0$ firms cooperate and at $t = 1$ both invest.

[15] 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?"

- If $f_1 \geq f > f_2$, we have $E\Pi_i^{NC}(I;NI) \geq 0$ and $E\Pi_i^{CC}(I;I) \geq 0$; then, at $t = 0$ firms cooperate if and only if $E\Pi_i^{CC}(I;I) \geq E\Pi_i^{NC}(I;NI)$; using equations 6 and 19 this is true if and only if $\frac{f^{CC}}{2} - \frac{f}{2} \geq f_1 - f$, that is $f \geq 2f_1 - f^{CC}$.
- if $f \leq f_2$, we have $E\Pi_i^{NC}(I;I) \geq 0$ and $E\Pi_i^{CC}(I;I) \geq 0$; then, at $t = 0$ firms cooperate if and only if $E\Pi_i^{CC}(I;I) \geq E\Pi_i^{NC}(I;I)$; using equations 8 and 19 this is true if and only if $\frac{f^{CC}}{2} - \frac{f}{2} \geq f_2 + \rho\beta\Pi^D - f$, that is $f \geq 2f_2 + 2\rho\beta\Pi^D - \rho\Pi^M = 2f_2 + \beta f_C - f^{CC}$.

■

Proposition 6 implies that collusion enlarges the parameter set where cooperation emerges as equilibrium, this is due to the increased cooperative expected profits.

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

$$EW^{CC}(I;I) = \rho W^M - f \tag{20}$$

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

$$f_w^{CC} = \rho W^M \tag{21}$$

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. $f \geq \widehat{f}^{CC} = \rho(\left(W^D - W^M\right)(2\beta(1-\rho) + \rho) + W^M(1-\rho))$; however it is possible to show that $\widehat{f}^{CC} > f^{CC}$, hence $f \geq \widehat{f}^{CC}$ 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 to no firm investing 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 20. ■

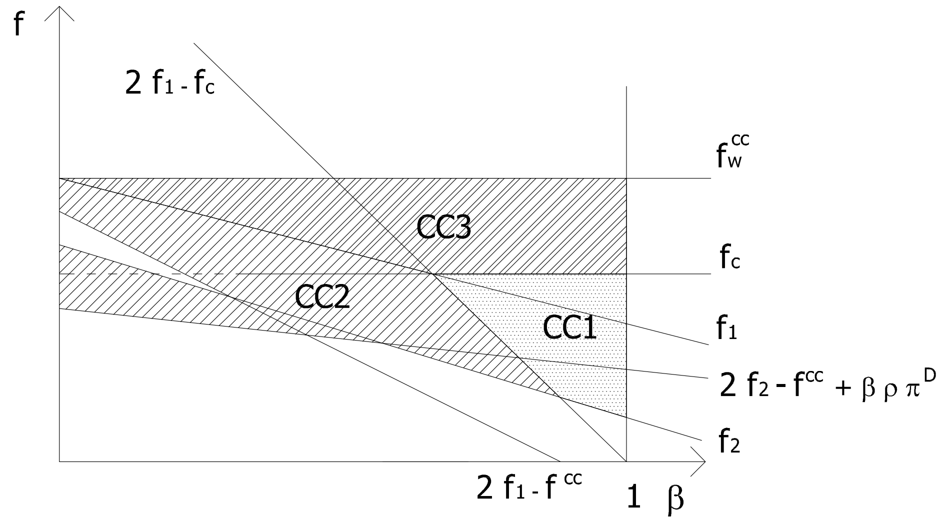

Figure 4: Cooperation as SPNE of the modified game..

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) firms cooperate and invest 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 subsides 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 shadow costs of public funds high enough.

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 $s = f/2 - \rho\Pi^D$.*

Proof. Without collusion cooperation does not emerge as equilibrium in the set of parameters β and f described in case (d_1) of Proposition 5. In such subset, we have that $EW^{CC}(I;I) \geq EW^C(I;I) - \lambda s$ if and only if $\lambda > \lambda(s) = \frac{\rho(W^D - W^M)}{f/2 - \rho\Pi^D}$. ■

Proposition 7 states that when the subsidy s requited to cooperate is high, the probability to innovate ρ 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 λ 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 extended the results of the literature to the context of product innovation. Our results confirm that spillovers reduce private incentive to invest and stimulate cooperation. Moreover we have showed that cooperation may not be the social optimum and, as a consequence, subsidizing any form of R&D cooperation is not socially efficient. We have pointed out cases where cooperation is efficient and emerges spontaneously as SPNE (subsides are a waste of public funds), cases where cooperation is efficient but does not emerges (subsides are necessary). Finally, introducing collusion in the market, as an alternative scenario, increases the private incentive to invest and cooperate in R&D, reducing the cases where firms need public subsides. We proved that when subsidies are costly to the taxpayers, collusion may lead to a social welfare improvement.

Our analysis can be developed introducing vertical or horizontal differentiation in the model.

References

Almus, and Czarnitzki, D., 2003, "The effects of public R&D subsidies on firms' innovation activities: the case of Eastern Germany", Journal of Business and Economic Statistics 21(2), 226–236.

Becker, B., 2015, "Public R&D policies and private R&D investment: a survey of the empirical evidence", Journal of Economic Surveys, 29: 917–942.

Busom, I. 2000, "An empirical evaluation of the effects of R&D subsidies", Economics of Innovation and New Technology, 9(2), 111–148.

Belleflamme, P. and M. Peitz, 2010, Industrial Organization. Markets and Strategies, Cambridge University Press.

Cabon-Dhersin, M.L., 2008, "R&D cooperation and collusion: the case of joint labs", The Manchester School, 76 (4): 424–435.

Cabral, L., 2000, "R&D cooperation and product market competition", International Journal of Industrial Organization 18: 1033-1047.

Choi, J.P., 1993, "Cooperative R&D with Product Market Competition", International Journal of Industrial Organization 11, 553-71.

Czarnitzki, D. and Fier, A., 2002, "Do innovation subsidies crowd out private investment? Evidence from the German Service Sector", Applied Economics Quarterly 48(1), 1–25.

d'Aspremont, C. and Jacquemine A., 1988, "Cooperative and noncooperative R&D in duopoly with spillovers", American Economic Review, 78(5), 1133-37.

Dimos, C. and Pugh, G., 2016, "The effectiveness of R&D subsidies: A meta-regression analysis of the evaluation literature", Research Policy, 45, 797–815.

Kamien, M. I., Muller E., and Zang I., 1992, "Research joint ventures and R&D cartels", The American Economic Review, 82(5), 1293-1306.

Goere M. and Helland E., "Do Research Joint Ventures Serve a Collusive Function?", IEW Working Paper Series no. 448, Zurich, Switzerland.

Gonzalez, X., Jaumandreu, J. and Pazo, C., 2005, "Barriers to innovation and subsidy effectiveness", RAND Journal of Economics, 36(4), 930–949.

Goyal, S. and Moraga-Gonzales J., 2001, "R&D networks", Rand Journal of Economics, 32 (4), 686-707.

Griliches, Z., 1992. "The Search for R&D Spillovers.", Scandinavian Journal of Economics 94(Supplement): 29-47.

Jaffe, A., 1989, "The Real Effects of Academic Research", American Economic Review 79: 957-970.

Lach, S., 2002, "Do R&D subsidies stimulate or displace private R&D? Evidence from Israel", Journal of Industrial Economics, 50(4), 369–390.

Lambertini, L., Poddar S., and Sasaki D., 2003, "RJVs in product innovation and cartel stability", Review of Economic Design, 7(4), 465-477

Leahy, D. and Neary P., 1997, "Public policies towards R&D in oligopolistic industries", The American Economic Review, 87 (4), 642-62.

Marinucci, M., 2012. "A primer on R&D cooperation among firms," Questioni di Economia e Finanza (Occasional Papers) 130, Bank of Italy, Economic Research and International Relations Area

Martin, S., 1995. "R&D joint ventures and tacit product market collusion". European Journal of Political Economy 11: 733-741.

Miyagiwa, K., 2009, "Collusion and Research Joint Ventures", Journal of Industrial Economics, 57 (4): 768–784.

Rebolledo, M. and Sandonis, J., 2012, "The effectiveness of R&D subsidies", Economics of Innovation and New Technology, 21 (8): 815–825.

Wallsten, S. J., 2000, "The effects of government-industry R&D programs on private R&D: the case of the Small Business Innovation Research Programm", RAND Journal of Economics, 31(1), 82–100.

Yao, Z. and Zheng, B., 2014, "R&D cooperation between impatient rivals", Bulletin of Economic Research, 68 (4): 396–413.