Discussion Paper No. 1105

RESEARCH JOINT VENTURES AND OPTIMAL R&D POLICY WITH ASYMMETRIC INFORMATION*

by

Bruno Cassiman**

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Abstract: Research Joint Ventures and subsidies are important R&D policy instruments. The regulator, however, is unlikely to know all the relevant information to regulate R&D optimally. The extent to which there are appropriability problems is one such variable that is private information to the firms within the industry. In a duopoly setting we analyze the characteristics of a first-best and second-best R&D policy where the government can either allow Research Joint Ventures or not and give lump-sum subsidies to the parties involved. The second-best R&D policy improves upon the policy of an unsophisticated government by integrating reports of the firms on their spillovers and the correlation between the R&D spillovers of the firms into its formulation.

*I would like to thank David Besanko, Pierre Regibeau, Asher Wolinsky and Patrick Greenlee for many helpful discussions and comments. All remaining errors are mine.

** J. L. Kellogg Graduate School of Management, Department of Managerial Economics and Decision Sciences. Financial Assistance of the National Fund for Scientific Research, Belgium is gratefully acknowledged.

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Research Joint Ventures and Optimal R&D Policy with Asymmetric Information

I. Introduction

Recent research in Industrial Organization has focused on modeling Research and Development (R&D) as a decision and/or strategic variable in the economic process. Two features distinguish R&D from ordinary capital investments. First, R&D is a public good (Arrow (1962), Grossman and Shapiro (1986)). The use by one firm of the information produced by its R&D investments does not diminish the amount of information available to other firms. The optimal economy wide allocation would therefore involve the free distribution of this information. Second, R&D investment is plagued by an externality problem. Firms investing in R&D typically can not fully appropriate the results from their own R&D investments. Knowledge spillovers occur between firms in the market. From a welfare perspective these spillovers are actually welfare improving but they tend to undermine the firms incentives to conduct R&D. The effect of these spillovers have been examined in different market settings. The general findings agree on the fact that spillovers tend to reduce the incentive to invest in R&D when firms act noncooperatively. This result is primarily due to Spence (1984), and has been confirmed in several other settings: d'Aspremont and Jacquemin (1988), De Bondt and Veugelers (1991), Kamien, Muller and Zang (1992) and others.[1]

In the classical literature on public goods and externalities several solutions to these market failures have been proposed. In this paper we concentrate on two policy options that seem very reasonable in a R&D setting: internalization of the externality and subsidies (Katz and Ordover (1990)). One way to internalize the appropriability problem is to form Research Joint Ventures (RJV). In a RJV the firms internalize the positive effect these spillovers have on the R&D and profits of their partners by deciding jointly on their R&D investments, taking their spillovers into account. When firms are allowed to form RJV's, R&D investments increase with the level of spillovers, exceeding the noncooperative investment level when the spillovers are substantial (d'Aspremont and Jacquemin (1988), De Bondt and Veugelers (1991)). Firms that compete on the output market but cooperate in R&D might thus not only increase profits but also welfare when the spillovers are substantial. Policy wise, a case can be made for allowing RJV's to form when there are high spillovers in R&D: RJV's solve the appropriability problem, R&D investments increase and welfare improves. However when there are low or no spillovers, firms acting noncooperatively with respect to R&D bring about higher welfare than when allowed to form a RJV. Through a RJV firms commit to reduce their investments in R&D, which in turn decreases welfare (Katz (1986)).

This theoretical finding has fuelled the debate on the issue of relaxing antitrust regulation with respect to RJV's. Everybody agrees on the benefits due to internalizing the externality by means of a RJV when the information leakage is substantial (Jacquemin and Soete (1994)). However the debate on the exact implementation of this policy is still ongoing. In evaluating cooperative R&D regulators still use the same "rule of reason" as in the case of mergers. Given the dynamic nature of R&D, insensitive application of these static merger guidelines may lead to undesirable outcomes (Ordover and Willig (1985)). Appropriate standards for evaluating RJV's should be developed. Jorde and Teece (1990) propose a procedure for evaluating and possibly certifying cooperative R&D agreements in order to create a safe harbor from antitrust litigation. Shapiro and Willig (1990) claim that this would amount to giving RJV's a blank check. A regulator needs a great deal of information to evaluate a RJV and much of this information might be proprietary. In fact the spillover level of individual firms may be private information of the firms within the industry. Scott (1988) notes that evidence on the effect of the National Cooperative Research Act (NCRA) suggests that cooperative research registered under the NCRA does not happen in industries with severe appropriability problems. By registering under the NCRA act, firms become exempt from treble damages under antitrust regulation. However, cooperative R&D ventures need not register under the NCRA, but in that case they are liable under the usual antitrust regulation. Scott's (1988) finding is indicative of asymmetric information with a resulting adverse selection of low spillover firms that register under the NCRA. RJV's formmed by these firms most likely decrease welfare. Firms that form RJV's and do not register under the NCRA act, consider antitrust charges extremely unlikely because their cooperative agreements do not conflict with regulatory objectives.

Changing antitrust regulation with respect to the evaluation of RJV's might not be sufficient to improve welfare. Providing funding to R&D performing firms might be the key to inducing the firms to engage in welfare increasing RJV's. Proposals to change U.S.

antitrust regulation with respect to RJV's have never considered subsidizing the firms. Europe and Japan, however, have R&D policies that both allow RJV's and provide extra funding (Brodley (1990), Jacquemin (1988)). Subsidies thus provide an additional R&D policy instrument to improve the allocation of resources to R&D investments. Subsidies can be lump-sum transfers which implement the R&D policy or per unit R&D subsidies which impact on the marginal incentive to invest in R&D. Spence (1984) documents the positive effect of subsidies per unit of R&D. The more severe the appropriability problem is, the higher the resulting welfare performance of subsidies. However, we concentrate only on lump-sum subsidies that implement the R&D policy because per unit subsidies create additional incentive problems in reporting the true level of R&D investments. Brown (1984) noted a significant increase in R&D expenditures reported on tax forms in response to the tax credit for increases in R&D spending of the 1981 Economic Recovery Act. The increase greatly exceeded the growth in spending reported in Business Week's survey of R&D expenditures. This divergence between growth rates is consistent with the existence of an informational problem in reporting the true level of R&D expenditures. Lump-sum subsidies do not create these additional problems and can easily be implemented through fixed price government contracts as the European Community does in subsidizing cooperative R&D.

In our model the government (or regulator)[2] has two R&D policy instrument at its disposal. First the government can allow or prohibit RJV formation. We assume that firms cannot be forced into a RJV against their will, so that RJV's form only when profitable.

The regulatory policy analyzed here consists of an evaluation process which allows RJV's to form with a certain probability. The second policy instrument is subsidizing R&D of competing firms or of a RJV where subsidies are assumed to be lump-sum transfers. The regulator chooses its policy in order to maximize social welfare taking into account its information disadvantage regarding the true level of R&D spillovers. The resulting policy can be formulated as follows: firms wishing to engage in cooperative research apply to the government for permission. Firms simultaneously and independently report their own spillover level to the government. The probability that a RJV will be approved and the level of lump-sum subsidies is a function of these reports. This is an implementation problem with asymmetric information between a regulator and an oligopoly.[3]

In the next section we set up the general model. In section three we solve the model for the case where no subsidies are provided. Next we solve the general model with lump-sum subsidies. Finally, we conclude by concentrating on policy recommendations. In Appendix B we show that the model of d'Aspremont and Jacquemin (1988) is consistent with our more general model. Due to their simple nature, proofs are relegated to Appendix A.

II. The Model

Consider a duopoly where each firm invests in R&D and then competes in the output market. R&D investment spillovers can either be High (H) or Low (L). A high spillover for firm i means that firm i absorbs a great deal of the knowledge of firm j. Firms only know their own spillover. Beliefs about a rival's spillover, conditional on a firm's own spillover, are summarized by a probability distribution. The firms are symmetric except possibly for their spillover. In the R&D stage the firms can either compete in R&D or form a RJV that is precompetitive[4], meaning that the firms cooperate in R&D but they are required to compete in the output market.

The government's objective is to maximize social welfare using a R&D policy with two instruments:

1. allowing research joint ventures (RJV's) or not,
2. giving lump sum subsidies to the firms.

The government has a probability distribution over the states of the world and there are four states of the world:

$$\text{States} = \{(L, L), (L, H), (H, L), (H, H)\},$$

i.e. both firms have low spillovers, one firm has a low spillover while the other has a high spillover or both firms have high spillovers.

The timing of the game is as follows: the government commits to its R&D policy after which the firms simultaneously submit claims about their spillover level. The true state of the world is revealed to the firms after they filed their reports. They subsequently make their R&D and output decisions with perfect information.[5]

Let β_i be the spillover level of firm i. The beliefs of the government and firms are given by:

Government's Beliefs:

$$\text{Prob}(\beta_1=L,\ \beta_2=L) = p_{LL},$$
$$\text{Prob}(\beta_1=L,\ \beta_2=H) = \text{Prob}(\beta_1=H,\ \beta_2=L) = p_{LH},$$
$$\text{Prob}(\beta_1=H,\ \beta_2=H) = p_{HH},$$
$$\text{where } p_{LL} + 2p_{LH} + p_{HH} = 1.$$

Firm i's Beliefs:

$$\text{Prob}(\beta_j = L \mid \beta_i = L) = p_{LL} / (p_{LL} + p_{LH}) = \alpha,$$
$$\text{Prob}(\beta_j = L \mid \beta_i = H) = p_{LH} / (p_{LH} + p_{HH}) = \gamma.$$

Define the R&D policy f as follows:

f: States --> [0,1] x R_+ x R_+ such that $f(\hat{\beta}_i,\hat{\beta}_j) = [r_{\hat{\beta}\hat{\beta}}, S^i_{\hat{\beta}\hat{\beta}}, S^j_{\hat{\beta}\hat{\beta}}]$

where $r_{\hat{\beta}\hat{\beta}}$ is the probability that the government allows a RJV and $S^i_{\hat{\beta}\hat{\beta}}$ is the subsidy given to firm i when firm i reports its spillover as being $\hat{\beta}_i$ and firm j reports $\hat{\beta}_j$.[6]

Since the subsidies are lump-sum, they will not influence the firms' R&D and output decisions. Let $V^{nc}(\beta_i,\ \beta_j)$ be firm i 's profits without subsidies when the firms are not allowed to form a RJV (noncooperative) in state $(\beta_i,\ \beta_j)$ and $V^{c}(\beta_i,\ \beta_j)$ when they are allowed to form a RJV (cooperative). Similarly define $W^{nc}(\beta_i, \beta_j)$ as the social welfare resulting in state (β_i, β_j) when the firms are not allowed to form a RJV and $W^{c}(\beta_i, \beta_j)$ when they form a RJV in state (β_i, β_j).

We make the following assumptions:[7]

A1: $W^{nc}(L, L) > W^{c}(L, L)$.

A2: $W^{c}(H, H) > W^{nc}(H, H)$.

A3: $W^{c}(L, H) = W^{c}(H, L) > W^{nc}(L, H) = W^{nc}(H, L)$.

A4: $V^{c}(\beta_1, \beta_2) > V^{nc}(\beta_1, \beta_2) \quad \forall\ \beta_i \in \{L, H\}$.

In state (L, L) welfare is higher when the firms do not form a RJV (A1). If there are little or no appropriability problems, society is served by firms competing in R&D. Firms use R&D strategically to secure market share in the output market. The RJV restricts R&D compared to the noncooperative case, leading to higher production costs and lower output which reduces welfare (Katz (1986)).

In the case of severe appropriability problems, total welfare is increased by the formation of a RJV (d'Aspremont and Jacquemin (1988), Katz and Ordover (1990)). When competing in R&D, firms restrict their R&D expenditures since much of a firm's research output flows to its rival. This externality is internalized by a RJV and as a result society benefits because of increased R&D investments, lower production costs and consequently a higher output at lower prices (A2).[8]

If the spillovers are different we assume that welfare is higher if both firms join in a RJV (A3).[9] The low spillover firm restricts its R&D investments significantly more compared to the state where its rival also has a low spillover. Forming a RJV restores the incentives of the low spillover firm to invest in R&D. The increased knowledge flows freely to the high spillover firm. In response the high spillover firm reduces its own R&D investments slightly. Whenever the increase in R&D investment of the low spillover firm outweighs the reduction of R&D by the high spillover firm, welfare is improved by the formation of a RJV. Since the RJV's are precompetitive, the high spillover firm can maintain a competitive advantage by not reducing its R&D investment by the same amount as the low spillover firm increases its R&D in a RJV and thus capturing a larger market share in the output market.[10]

Firms always prefer to form a RJV (A4). The least a RJV can do is coordinate the R&D investments of both firms such that total joint profits are maximized. If we assume that transfers are allowed in the case of a RJV, the firms will always prefer the RJV to competition in R&D.

Under perfect information the government will allow RJV's if at least one of the firms has a high spillover. If both firms have a low spillover they will be required to compete in R&D. If there is a cost of public funds, λ, the regulator will not use any subsidies since they are merely a transfer of funds. Every dollar spent by the government, costs society $1+\lambda$ dollars.

The first-best policy f* maximizes social welfare. It is given by:

$$f^*(L, L) = [\,0, 0, 0],$$

$$f^*(L, H) = f(H, L) = [1, 0, 0],$$

$$f^*(H, H) = [1, 0, 0].$$

When the spillover level of a firm is private information, the first-best policy is not feasible. A conflict arises between the government's objective and a firm's objective in the state (L, L). A low spillover firm has an incentive to claim that its spillover is high. By doing so, the firm can guarantee approval of a RJV, which it prefers by (A4). To solve this problem the government must adjust its R&D policy to reflect firms' incentives to misreport their private information. Because of the revelation principle the government can restrict attention to mechanisms that require the firms to report truthfully and give no incentive to cheat (Baron and Myerson (1982), Baron (1989)).

The government has to solve the following program:

$$MAX_{\{r_{LL},\, r_{LH},\, r_{HH},\, S_{LL},\, S_{LH},\, S_{HL},\, S_{HH}\}} EW$$

$$= Wo + p_{LL}\,[W^c(L, L) - W^{nc}(L, L)]\, r_{LL} + 2\, p_{LH}\,[W^c(L, H) - W^{nc}(L, H)]\, r_{LH}$$

$$+ p_{HH}\,[W^c(H, H) - W^{nc}(H, H)]\, r_{HH} - 2\lambda\,[p_{LL}\, S_{LL} + p_{LH}\, S_{HL} + p_{LH}\, S_{LH} + p_{HH}\, S_{HH}],$$

subject to:

IC(L) $[V^{nc}(L, L) - V^{c}(L, L)]\, r_{LL} + [V^{c}(L, L) - V^{nc}(L, L) - \alpha^*[V^{c}(L, H) - V^{nc}(L, H)]]\, r_{LH}$

$$+ \alpha^* [V^{c}(L, H) - V^{nc}(L, H)]\, r_{HH} + S_{HL} + \alpha^* S_{HH} \le S_{LL} + \alpha^* S_{LH}.$$

IC(H) $[V^{c}(H, L) - V^{nc}(H, L)]\, r_{LL} - [V^{c}(H, L) - V^{nc}(H, L) - \gamma^*[V^{c}(H, H) - V^{nc}(H, H)]]\, r_{LH}$

$$- \gamma^*[V^{c}(H, H) - V^{nc}(H, H)]\, r_{HH} + S_{LL} + \gamma^* S_{LH} \le S_{HL} + \gamma^* S_{HH}.$$

$0 \le r_{LL} \le 1.$
$0 \le r_{LH} \le 1.$
$0 \le r_{HH} \le 1.$

$S_{LL} \ge 0.$
$S_{LH} \ge 0.$
$S_{HL} \ge 0.$
$S_{HH} \ge 0,$

where EW is the expected welfare of society, and

$Wo = p_{LL}\, W^{nc}(L, L) + p_{LH}\, W^{nc}(L, H) + p_{HH}\, W^{nc}(H, H),$

λ is the cost of public funds,

$\alpha^* = (1-\alpha) / \alpha$ is the ratio of $Prob(\beta_j=H \mid \beta_i=L)$ to $Prob(\beta_j=L \mid \beta_i=L)$, and

$\gamma^* = (1-\gamma) / \gamma$ is the ratio of $Prob(\beta_j=H \mid \beta_i=H)$ to $Prob(\beta_j=L \mid \beta_i=H)$.[11]

IC(L) is the incentive constraint corresponding to truthful revelation by the low spillover type, while IC(H) is the incentive constraint for the high spillover type. Note that the right hand side of the IC constraints is the expected subsidy that a firm of that type gets. Since the subsidies are restricted to be non-negative the Individual Rationality constraints are trivially satisfied if the profit levels in the cooperative and the noncooperative case are non-negative. The probabilities are restricted to lie between zero and one.

Next we consider two cases. In the first case the regulator can not give any subsidies. The only policy instrument is the probability with which to allow RJV's. In the second case the regulator can use lump-sum subsidies together with allowing RJV's or not as a means of R&D policy.

III. CASE I: No Subsidies

In the no-subsidy case the only policy tool in the hands of the government is the probability with which to allow a RJV. This simplifies the problem that the government has to solve considerably. Suppose that an unsophisticated government ignores the private information of the firms and only allows or prohibits the RJV based on its own beliefs. This leads to the following result:

Proposition 1:

Let $U = W^c(L, L) - W^{nc}(L, L) + 2\ \alpha^*\ [W^c(L, H) - W^{nc}(L, H)] + \alpha^*\gamma^*\ [W^c(H, H) - W^{nc}(H, H)]$.

If $U \geq 0$, the government will always allow RJV's, while if $U < 0$, no RJV will be allowed.

To understand the economic intuition of the following propositions, it is more informative to reformulate the problem in terms of the marginal probabilities and correlation of the types.

Let: $\theta = p_{LL} + p_{LH}$ be the marginal probability of type L,

$1\text{-}\theta = p_{LH} + p_{HH}$ is the marginal probability of type H,

$\rho = \text{corr}(\beta_1, \beta_2)$ is the correlation between the types of the firms,

where $0 < \theta < 1$ and $-1 < \rho \leq 1$.[12]

It is fairly straight forward to translate all conditions in terms of marginals and correlation. The expressions, however, become highly non linear with:[13]

$$\alpha^* = \frac{(1-\rho)(1-\theta)}{\rho+(1-\rho)\theta},$$

$$\gamma^* = \frac{(1-\theta)+\rho\theta}{(1-\rho)\theta}.$$

Figure 1 explores the relation between the government beliefs about the state of the industry on the one hand and the marginal probability of the low spillover type and the correlation between the types in the industry on the other. For a given marginal probability of the low type, θ, an increase in the correlation between the types of the firms in the industry, ρ, implies that both the states (L, L) and (H, H) become more likely while the asymmetric states (L, H) and (H, L) are less probable. For a given level of correlation, an increase of the marginal probability of the low spillover type, θ, always increases the probability of the state (L, L) while decreasing the likelihood of the state (H, H). For $\theta < ½$, the probability of states (L, H) and (H, L) increases with θ, while for $\theta > ½$, these probabilities decrease.

In Figure 2 the R&D policy of an unsophisticated government (Proposition 1) is depicted. The values of (ρ, θ) for which a RJV should be allowed to form are shown. The regulator allows RJV's when the marginal probability of the low spillover type, θ, is low. RJV most likely are welfare improving in this region. As the marginal probability of the low spillover type increases, there is a point (U=0)[14] at which the R&D policy changes to not allowing any RJV's.

The government can improve upon this policy by using firm reports about their spillovers. However, the Incentive Constraints come in to play. The relation between IC(L) and IC(H) are examined in Appendix A.

Define the following critical cutoffs:

$$\bar{\alpha}^* = \frac{V^{J}(L,L)-V^{NJ}(L,L)}{V^{J}(L,H)-V^{NJ}(L,H)},$$

$$\hat{\alpha}^* = \frac{[V^{J}(L,L)-V^{NJ}(L,L)][W^{NJ}(L,L)-W^{J}(L,L)]}{2[V^{J}(L,L)-V^{NJ}(L,L)][W^{J}(L,H)-W^{NJ}(L,H)]+[V^{J}(L,H)-V^{NJ}(L,H)][W^{NJ}(L,L)-W^{J}(L,L)]},$$

$$\hat{\gamma}^* = \frac{[V^{J}(L,H)-V^{NJ}(L,H)][W^{NJ}(L,L)-W^{J}(L,L)]}{[V^{J}(L,L)-V^{NJ}(L,L)][W^{J}(H,H)-W^{NJ}(H,H)]}.$$

It is easy to show that $\hat{\alpha}^* \leq \bar{\alpha}^*$ when (A3) and (A4) hold.

These cutoffs define five important regions in the (α^*, γ^*) belief space:

$$R_{(1)}=\{(\alpha^*,\gamma^*) \mid \alpha^* \geq \hat{\alpha}^*, \gamma^* \geq \hat{\gamma}^*\},$$
$$R_{(2)}=\{(\alpha^*,\gamma^*) \mid \alpha^* \leq \hat{\alpha}^*, \gamma^* \leq \hat{\gamma}^*\},$$
$$R_{(3)}=\{(\alpha^*,\gamma^*) \mid \alpha^* \leq \hat{\alpha}^*, \gamma^* \geq \hat{\gamma}^*\},$$
$$R_{(4)}=\{(\alpha^*,\gamma^*) \mid \hat{\alpha}^* \leq \alpha^* \leq \bar{\alpha}^*, \gamma^* \leq \hat{\gamma}^*\},$$
$$R_{(5)}=\{(\alpha^*,\gamma^*) \mid \alpha^* \geq \bar{\alpha}^*, \gamma^* \leq \hat{\gamma}^*\}.$$

Since subsidies are zero, the R&D policy simplifies to $f(\beta_i,\ \beta_j) = r_{\beta_i\beta_j}$. We now formulate the second-best R&D policy:

<u>Proposition 2:</u>

Let

$$IH_{(3)} = R_{(3)} \cap \{(\alpha^*,\gamma^*) | \gamma^* \leq \alpha^* \frac{[V^c(L,H)-V^{nc}(L,H)][V^c(H,L)-V^{nc}(H,L)]}{[V^c(L,L)-V^{nc}(L,L)][V^c(H,H)-V^{nc}(H,H)]}\},$$
$$IH_{(4)} = R_{(4)} \cap \{(\alpha^*,\gamma^*) | \gamma^* \geq \alpha^* \frac{[V^c(L,H)-V^{nc}(L,H)][V^c(H,L)-V^{nc}(H,L)]}{[V^c(L,L)-V^{nc}(L,L)][V^c(H,H)-V^{nc}(H,H)]}\},$$
$$IH_{(5)} = R_{(5)} \cap \{(\alpha^*,\gamma^*) | \gamma^* \geq \alpha^* \frac{[V^c(L,H)-V^{nc}(L,H)]}{[V^c(H,H)-V^{nc}(H,H)]}\}.$$

The second best mechanism f^{SB} is as follows:

(1) if $(\alpha^*,\ \gamma^*) \in R_{(1)}$ then
$$r_{LL}^{SB} = 1,\quad r_{LH}^{SB} = 1,\quad r_{HH}^{SB} = 1.$$

(2) if $(\alpha^*,\ \gamma^*) \in R_{(2)}$ then
$$r_{LL}^{SB} = 0,\quad r_{LH}^{SB} = 0,\quad r_{HH}^{SB} = 0.$$

(3) if $(\alpha^*,\ \gamma^*) \in R_{(3)} \setminus IH_{(3)}$ then

$$r_{LL}^{SB} = \frac{\alpha^*[V^c(L,H)-V^{nc}(L,H)]}{V^c(L,L)-V^{nc}(L,L)} = p_{R_3}(\alpha^*), \tag{1}$$
$$r_{LH}^{SB} = 0,$$
$$r_{HH}^{SB} = 1.$$

(3') if $(\alpha^*,\ \gamma^*) \in IH_{(3)}$ then if $U \geq 0$, then $r_{\beta\beta}^{SB} = 1 \quad \forall \beta_k \in \{L,H\}$,

if $U < 0$, then $r_{\beta\beta}^{SB} = 0 \quad \forall \beta_k \in \{L,H\}$.

(4) if $(\alpha^*,\ \gamma^*) \in R_{(4)} \setminus IH_{(4)}$ then
$$r_{LL}^{SB} = \frac{V^c(L,L)-V^{nc}(L,L)-\alpha^*[V^c(L,H)-V^{nc}(L,H)]}{V^c(L,L)-V^{nc}(L,L)} = p_{R_4}(\alpha^*), \tag{2}$$

$$r_{LH}^{SB} = 1,$$
$$r_{HH}^{SB} = 0.$$

(4') if $(\alpha^*, \gamma^*) \in IH_{(4)}$ then if $U \geq 0$, then $r_{\beta\beta}^{SB} = 1 \quad \forall \beta_k \in \{L,H\}$,

if $U < 0$, then $r_{\beta\beta}^{SB} = 0 \quad \forall \beta_k \in \{L,H\}$.

(5) if $(\alpha^*, \gamma^*) \in R_{(5)} \setminus IH_{(5)}$ then

$$r_{LL}^{SB} = 0,$$
$$r_{LH}^{SB} = 1,$$
$$r_{HH}^{SB} = \frac{\alpha^*[V^c(L,H) - V^{nc}(L,H)] - [V^c(L,L) - V^{nc}(L,L)]}{\alpha^*[V^c(L,H) - V^{nc}(L,H)]} = \rho_{R_5}(\alpha^*). \qquad (3)$$

(5') if $(\alpha^*, \gamma^*) \in IH_{(4)}$ then if $U \geq 0$, then $r_{\beta\beta}^{SB} = 1 \quad \forall \beta_k \in \{L,H\}$,

if $U < 0$, then $r_{\beta\beta}^{SB} = 0 \quad \forall \beta_k \in \{L,H\}$.

<u>proof:</u> See Appendix A.

It is obvious that the second-best mechanism depends critically on the beliefs of the regulator and the firms. The probability of allowing a RJV changes as the underlying beliefs of the government and the firms change. The following comparative statics results w.r.t. ρ and θ on these probabilities will help to clarify the intuition of the second-best R&D policy:

Proposition 3:

$$\frac{\partial p_{R_{(3)}}(\rho,\theta)}{\partial \rho} < 0 \ , \quad \frac{\partial p_{R_{(3)}}(\rho,\theta)}{\partial \theta} < 0,$$

$$\frac{\partial p_{R_{(4)}}(\rho,\theta)}{\partial \rho} > 0 \ , \quad \frac{\partial p_{R_{(4)}}(\rho,\theta)}{\partial \theta} > 0,$$

$$\frac{\partial p_{R_{(5)}}(\rho,\theta)}{\partial \rho} < 0 \ , \quad \frac{\partial p_{R_{(5)}}(\rho,\theta)}{\partial \theta} < 0.$$

proof: See Appendix A.

Now we are ready to analyze the results of Proposition 2 in (ρ, θ)-space. In Figure 3 we report the second-best R&D policy for every region as [r_{LL}, r_{LH}, r_{HH}]. This second-best R&D policy reflects the fact that the regulator foremost has to worry about a low spillover firm lying about its true type. Since the firms and the regulator only have conflicting objectives when the true state of the industry is (L, L), the second-best policy screens out the state (L, L) whenever it is welfare increasing to do so.

In region $R_{(1)}$ the combined probability of states (H, H), (L, H) and (H, L) is high (1-θ high). In this case it will be too costly in welfare terms to screen out state (L, L) and the optimal R&D policy always allows RJV's. The lower the probability of state (L, L), the less distortionary this mechanism is compared to the first-best policy. As the correlation between the types increases, less weight is put on the asymmetric states (L, H) and (H, L) compared to the state (L, L). The boundary wiyh region $R_{(3)}$ indicates the point at which it becomes welfare increasing to screen out state (L, L) at the expense of the welfare in states (L, H) and (H, L).

In region $R_{(2)}$ no RJV's are allowed. If θ is high, the state (L, L) will be very likely while the occurrence of (H, H), (L, H) or (H, L) is negligible. It is, again, too costly to screen out state (L, L). Allowing no RJV's satisfies the incentives of low spillover firms to reveal their type truthfully. As the correlation between the types increases, the probability of the state (H, H) increases. At the boundary with region $R_{(3)}$ it becomes again worthwhile in welfare terms to separate the states.

In region $R_{(3)}$ there exists positive correlation between the types and most probability weight lies on states (L, L) and (H, H). The high types will be allowed to form a RJV while the low types will only get to form a RJV with probability $p_{R(3)}(\alpha^*)$, given by (1). The regulator uses the fact that the types are positively correlated against the firms. The firms are punished if the reports are (L, H) or (H, L) where the punishment consists of not allowing them to form a RJV. A low spillover firm refrains from lying because the probability that its rival is also a low spillover firm is high. By lying the report to the regulator most likely will be (H, L) in which case the firms are not allowed to form a RJV. The most likely report, when telling the truth, is a report (L, L) in which case there is at least a small probability of being allowed to form a RJV. From Proposition 3 follows that this probability will decrease as θ and ρ increase, i.e. as (L, L) becomes the more likely true state. A smaller probability of forming a RJV is sufficient to induce truthful revelation by a low spillover firm because lying is more likely to generate a report (H, L), in which case the firms are forced to compete in R&D. As the correlation between the types increases, the second-best policy converges to the first-best since the probability of forming a RJV in the state (L, L) goes to zero. Under perfect correlation, given that its rival reveals truthfully, a low spillover firm is indifferent between telling the truth or not. Whatever its report, the firms are not allowed to form a RJV. Note also that not allowing a RJV when reporting (L, H) or (H, L) is the harshest punishment the regulator can give since we did not assume any transfers between the government and the firms. Even in the case of subsidies, we purposely restrict them to be non-negative.

The last two regions, $R_{(4)}$ and $R_{(5)}$, involve negative correlation between the types. The probability p_{LH}, that the firms have different spillovers, is considered very high in both of these cases. A RJV is thus allowed if the firms announce (L, H) or (H, L). In region $R_{(5)}$ the regulator has to worry about the low-spillover firm lying, while the probability of (H, H) is still relatively high. The probability that the rival of a low spillover firm has a high spillover, is very high. Truthful reporting by the low spillover firm results most likely in a report (L, H). In this case the firms will be allowed to form a RJV for sure. If the low spillover firm lies, the likely report is (H, H) and the firms only form a RJV with probability $p_{R(5)}(\alpha^*)$. Proposition 3 shows that the probability $p_{R(5)}(\alpha^*)$ decreases with a higher marginal probability of the low type. The lower probability deters the low spillover firm from lying as the probability of the true state (L, L) increases. Lying in the state (L, L) would guarantee the formation of a RJV. Decreasing the probability of approving a RJV in the state (H, H) increases the risk of lying to the low spillover firm up to the point that truthful reporting is preferred. On the boundary of region $R_{(5)}$ and $R_{(4)}$ the threat of a low firm lying has become so large (as θ increases) that the regulator cannot counter act it by decreasing the probability $p_{R(5)}(\alpha^*)$, which reaches zero at the boundary. From then onward the regulator must allow a positive probability of forming a RJV when the state is (L, L) to keep a low spillover firm truthful. Thes probability $p_{R(4)}(\alpha^*)$ of allowing a RJV in state (L, L) increases from zero on the boundary with $R_{(5)}$ up to the point where the state (L, L) becomes too likely. At that point the second-best R&D policy allows no RJV at all, and we are back in region $R_{(2)}$.

If the types are uncorrelated, the optimal policy switches from always allowing RJV's to not allowing RJV's in any state. This happens in region $IH_{(3)}$ in Figure 3. The IC(H) constraint is binding in region $IH_{(3)}$. The probability $p_{R(3)}(\alpha^*)$ of region $R_{(3)}$ becomes too high, and the high spillover type will lie if he puts high probability on the state being (H, L), i.e. if ρ is small. If the high spillover firm lies, the most likely report is (L, L), which results in the formation of a RJV with a high probability $p_{R(3)}(\alpha^*)$. Truthful revealing its type would lead to competition in R&D. Using Lemma 3 (see Appendix A), we know that the second-best policy in region $IH_{(3)}$ either allows RJV's in all states or never allows RJV's.[15] The R&D policy of an unsophisticated government would be optimal in this case (see Proposition 1).

IV. CASE II: Lump-Sum Subsidies

We now turn to the case where in addition to allowing RJV's or not, the regulator can also provide a lump-sum subsidy. The government has to solve the general program defined in section 2.

Define $\bar{\alpha}^*$, $\hat{\alpha}^*$ and $\hat{\gamma}^*$ as before, and let:

$$\lambda^* = \frac{W^{nrj}(L,L)-W^{rj}(L,L)}{2[V^{rj}(L,L)-V^{nrj}(L,L)]},$$

$$\hat{\alpha}^*(\lambda) = \frac{\lambda[V^{rj}(L,L)-V^{nrj}(L,L)]}{W^{rj}(L,H)-W^{nrj}(L,H)+\lambda[V^{rj}(L,H)-V^{nrj}(L,H)]},$$

$$\hat{\gamma}^*(\lambda) = \frac{2\lambda[V^{rj}(L,H)-V^{nrj}(L,H)]}{W^{rj}(H,H)-W^{nrj}(H,H)}.$$

It is easy to show that $\hat{\alpha}^*(\lambda) \le \hat{\alpha}^* \quad \forall\, \lambda \le \lambda^*$ and $\lim_{\lambda \to \lambda^*} \hat{\alpha}^*(\lambda) = \hat{\alpha}^*$, and

$\hat{\gamma}^*(\lambda) \le \hat{\gamma}^* \quad \forall\, \lambda \le \lambda^*$ and $\lim_{\lambda \to \lambda^*} \hat{\gamma}^*(\lambda) = \hat{\gamma}^*$.

These cutoffs define five important regions in (α^*, γ^*) belief space:

$$R\lambda_{(1)} = \{(\alpha^*,\gamma^*) \mid \alpha^* \ge \hat{\alpha}^*(\lambda), \gamma^* \ge \hat{\gamma}^*(\lambda)\},$$
$$R\lambda_{(2)} = \{(\alpha^*,\gamma^*) \mid \alpha^* \le \hat{\alpha}^*(\lambda), \gamma^* \le \hat{\gamma}^*(\lambda)\},$$
$$R\lambda_{(3)} = \{(\alpha^*,\gamma^*) \mid \alpha^* \le \hat{\alpha}^*(\lambda), \gamma^* \ge \hat{\gamma}^*(\lambda)\},$$
$$R\lambda_{(4)} = \{(\alpha^*,\gamma^*) \mid \hat{\alpha}^*(\lambda) \le \alpha^* \le \bar{\alpha}^*, \gamma^* \le \hat{\gamma}^*(\lambda)\},$$
$$R\lambda_{(5)} = \{(\alpha^*,\gamma^*) \mid \alpha^* \ge \bar{\alpha}^*, \gamma^* \le \hat{\gamma}^*(\lambda)\}.$$

This leads to:

Proposition 4: If $\lambda \ge \lambda^*$, then the second best mechanism f^{SB} coincides with the no subsidy case.

Proof: See Appendix A.

The intuition for the subsidy case follows closely that of the no-subsidy case. The ability to subsidize the firms increases the policy options of the government. It follows that welfare cannot decrease. At worse, if public funds are extremely costly, no subsidies will be used as an R&D policy tool and the government will either allow RJV's or not as described in Proposition 2. The critical level of cost of funds λ^* is determined by the ratio of the gain in total welfare of not allowing a RJV in the state (L, L) to the gain in total producer surplus by the formation of a RJV in the state (L, L).

<u>Proposition 5:</u> Suppose $\lambda \leq \lambda^*$,
When only IC(L) is binding, the second best mechanism f^{SB} is as follows:

(1) if $(\alpha^*, \gamma^*) \in R\lambda_{(1)}$ then
$$\begin{aligned} f^{SB}(L,L) &= [0, S^1_{LL}, S^2_{LL}], \\ f^{SB}(L,H) &= [1, S^1_{LH}, 0], \\ f^{SB}(H,L) &= [1, 0, S^2_{LH}], \\ f^{SB}(H,H) &= [1, 0, 0]. \end{aligned}$$

where $S^i_{LL} + \alpha^* S^i_{LH} = V^c(L,L) - V^{nc}(L,L)$.

(2) if $(\alpha^*, \gamma^*) \in R\lambda_{(2)}$ then $f^{SB}(\beta_i, \beta_j) = [0, 0, 0]$, $\forall\ \beta_k \in \{L, H\}$.

(3) if $(\alpha^*, \gamma^*) \in R\lambda_{(3)}$ then
$$\begin{aligned} f^{SB}(L,L) &= [0, S^1_{LL}, S^2_{LL}], \\ f^{SB}(L,H) &= [0, S^1_{LH}, 0], \\ f^{SB}(H,L) &= [0, 0, S^2_{LH}], \\ f^{SB}(H,H) &= [1, 0, 0]. \end{aligned}$$

where $S^i_{LL} + \alpha^* S^i_{LH} = \alpha^* [V^c(L,H) - V^{nc}(L,H)]$.

(4) if $(\alpha^*, \gamma^*) \in R\lambda_{(4)}$ then
$$\begin{aligned} f^{SB}(L,L) &= [0, S^1_{LL}, S^2_{LL}], \\ f^{SB}(L,H) &= [1, S^1_{LH}, 0], \end{aligned}$$

$$f^{SB}(H,L) = [1, 0, S_{LH}^{2}],$$
$$f^{SB}(H,H) = [0, 0, 0].$$

where $S_{LL}^{i} + \alpha^{*} S_{LH}^{i} = V^{c}(L,L) - V^{nc}(L,L) - \alpha^{*}[V^{c}(L,H) - V^{nc}(L,H)]$.

(5) if $(\alpha^{*}, \gamma^{*}) \in R\lambda_{(5)}$ then

$$r_{LL}^{SB} = 0,$$
$$r_{LH}^{SB} = 1,$$
$$r_{HH}^{SB} = \frac{\alpha^{*}[V^{c}(L,H) - V^{nc}(L,H)] - [V^{c}(L,L) - V^{nc}(L,L)]}{\alpha^{*}[V^{c}(L,H) - V^{nc}(L,H)]} = p_{R_{5}}(\alpha^{*}).$$

proof: See Appendix A.
See Appendix A for conditions such that only IC(L) is binding.

If public funds are not very costly, then subsidies will be used as an extra means of screening for the state (L, L). In this case, subsidies eliminate nearly all the inefficiencies that arise in the no-subsidy case. Again it is useful to reformulate the problem in terms of marginal probabilities and correlation of the types. Figure 4 shows the relevant regions. To clarify the relation with the no-subsidy case, the original regions of the no-subsidy case are depicted in dotted lines. As public funds become more costly, the second-best R&D policy with subsidies converges to the no-subsidy case (see (4)).

In region $R\lambda_{(1)}$ the first-best policy is implemented. However, because public funds are costly, the first-best welfare level is not attained. The expected subsidy to a firm with a low spillover is equal to the gain in profit from forming a RJV in the state (L, L). Note also that the region of beliefs, $R\lambda_{(1)}$, in which this mechanism is sustained contains the region for which the government always allowed RJV's in the no-subsidy case, i.e. region

$R_{(1)}$.

The region for which no RJV's are allowed in any state, region $R\lambda_{(2)}$, is a subset of that region, $R_{(2)}$, in the no-subsidy case. In the no-subsidy case it was inefficient not to allow RJV's if the true states where (L, H), (H, L) and (H, H) in this region. Subsidies increase the power of the R&D policy. The trade off between subsidies and a more efficient R&D organization is positive for a subset of $R_{(2)}$ in the no-subsidy case. The size of this region depends on how costly public funds are.

In region $R\lambda_{(3)}$ the regulator reduces the expected subsidies (rents) to the low spillover types compared to the expected subsidies in region $R\lambda_{(1)}$. Allowing a RJV only in state (H, H) and not in the asymmetric states accomplishes this. The asymmetric states, (L, H) or (H, L) are so unlikely that this trade off is profitable in expected welfare terms. The subsidies will be set at the maximum in the state (L, H) or (H, L) (see proof Lemma 4). This keeps the low types honest because of the expected reward. A low spillover firm expects a high subsidy in the asymmetric state (L, H). The low spillover firm prefers this very unlikely but high subsidy to the formation of a RJV. Note that as the correlation of types increases the subsidy converges to zero and the second-best R&D policy converges to the first-best.

In regions $R\lambda_{(4)}$ and $R\lambda_{(5)}$, the asymmetric states are extremely likely. A RJV will always be allowed if the firms report (L, H) or (H, L). However if the marginal probability of being low (θ) becomes too high, the regulator will have to revert to subsidies to keep the low spillover firms truthful. This transition is continuous. As in the no-subsidy case, the probability $p_{R(5)}(\alpha^*)$ decreases to zero at the boundary with $R\lambda_{(4)}$ after which subsidies take over the role of probability $p_{R(4)}(\alpha^*)$ in the no-subsidy case. Subsidies are a more cost efficient means to create separation in region $R\lambda_{(4)}$.

V. Conclusions

Knowledge resulting from R&D investments is characterized by both an externality and a public good problem. By implementing a R&D policy that encourages cooperative R&D in industries with severe appropriability problems, the government increases social welfare. However, the extent to which appropriability problems exist in a specific industry, is usually private information. The government should set up its R&D policy taking this information problem into account.

The government and the firms have conflicting objectives whenever both firms have low spillovers. The optimal R&D policy screens for the state (L, L) except when either the state (L, L) or the state (H, H) is extremely likely. In the no-subsidy case the probability of allowing a RJV is determined such that a low spillover firm has no incentive to lie about its spillover in order to be allowed to form a RJV. If public funds are not too costly, lump-sum subsidies are a more efficient means to screen out the state (L, L). The expected subsidy compensates the low spillover firm for revealing truthfully. However, these lump-sum subsidies will not improve allocative efficiency of R&D at the margin. They only improve the screening capability of the government. Examining a two-part subsidy scheme with a fixed transfer and a per unit R&D subsidy is left for future research. The per unit R&D subsidies improve total welfare both in the case of R&D cooperation and competition. We expect to find similar distortions of the first best R&D policy, however, as in the case of lump-sum subsidies analyzed here.

The fact that rival firms can have different spillovers in the same industry, however small the probability, results in a non trivial R&D policy. The first-best policy cannot be implemented anymore. Any rational firm will claim to have a high spillover level in the hope to be allowed to form a RJV. In reality the types of the firms will most likely be positively correlated ($0 \leq \rho < 1$) within a given industry. Unlike an unsophisticated R&D policy where the regulator only allows RJV's or not based on its beliefs about the state of the industry, the second-best R&D policy uses the fact that the spillovers of the firms are correlated in its formulation. For low levels of correlation an unsophisticated R&D policy is also optimal in the no-subsidy case. If the marginal probability of the low spillover type, θ, is low, RJV's should always be allowed because the state (H, H) is very likely. With a high marginal probability of the low spillover type, RJV's should not be allowed. As the correlation between the types increases, the regulator can use this correlation to improve upon the unsophisticated R&D policy by punishing asymmetric state reports by the firms. A low spillover firm will then refrain from lying. A carefully structured lump-sum subsidy program gets the second-best R&D policy even closer to the first-best.

Appendix A

From the (A1) - (A4) we can immediately derive the following result:

Lemma 1: At the optimal mechanism either IC(L) is binding or IC(L) and IC(H) are both binding.

Proof:

Just plug in the first best mechanism:
IC(L) becomes: $V^{c}(L, L) - V^{nc}(L, L) \leq 0$, which is clearly violated by (A4).
IC(H) becomes: $-V^{c}(H, L) + V^{nc}(H, L) \leq 0$ which is satisfied by (A4).
Thus IC(L) will have to be binding at the second best mechanism. ■

This obvious result will guide our solution process. First we solve for the optimal mechanism supposing that IC(L) is the only binding constraint. Afterwards we check for conditions such that IC(H) holds. If these conditions are violated we solve the model for the region where IC(H) is violated such that both constraints are binding.

Proof of Proposition 2
In a first step the problem is solved by assuming IC(L) is the only binding constraint. In a following step some Lemma's derive when IC(L) is the only binding constraint and what happens if both IC(L) and IC(H) are binding.

STEP 1:
This is a standard linear programming problem with one constraint. A nice method to solve this, is by comparing relative coefficients of the variables (coefficient in the objective function divided by the coefficient in the constraint). The variable with the highest ratio is increased (or decreased) to is boundary or as long as the constraint is satisfied. If there is still some slack, the variable with the next highest ratio is taken and so on.

The coefficient on r_{LL} *is* $\frac{p_{LL}[W^{nc}(L,L)-W^{c}(L,L)]}{V^{c}(L,L)-V^{nc}(L,L)}$.
The coefficient on r_{LH} *is* $\frac{2p_{LH}[W^{c}(L,H)-W^{nc}(L,H)]}{V^{c}(L,L)-V^{nc}(L,L)-\alpha^{*}[V^{c}(L,H)-V^{nc}(L,H)]}$.
The coefficient on r_{HH} *is* $\frac{p_{HH}[W^{c}(H,H)-W^{nc}(H,H)]}{\alpha^{*}[V^{c}(L,H)-V^{nc}(L,H)]}$.

Clearly the coefficients on r_{LL} and r_{HH} are positive by (A1), (A2) and (A4).
(AA1). If $\alpha^{*} \geq \frac{V^{c}(L,L)-V^{nc}(L,L)}{V^{c}(L,H)-V^{nc}(L,H)} = \bar{\alpha}^{*}$, the coefficient of r_{LH} is negative. This implies that since the coefficient of r_{LH} in the objective function is positive, we want to increase r_{LH} to its boundary, $r_{LH} = 1$. This will not make the constraint any tighter.

(AA2). The coefficient of $r_{LL} \geq r_{HH}$ if and only if

$$\gamma^{*} \leq \frac{[V^{c}(L,H)-V^{nc}(L,H)][W^{nc}(L,L)-W^{c}(L,L)]}{[V^{c}(L,L)-V^{nc}(L,L)][W^{c}(H,H)-W^{nc}(H,H)]} = \hat{\gamma}^{*}.$$

If $\alpha^* \leq \bar{\alpha}^*$, compare the coefficient of r_{LH} with the other two.

(AA3). The coefficient of $r_{LL} \geq r_{LH}$ if and only if

$$\alpha^* \leq \frac{[V^c(L,L)-V^{nc}(L,L)][W^{nc}(L,L)-W^c(L,L)]}{2[V^c(L,L)-V^{nc}(L,L)][W^c(L,H)-W^{nc}(L,H)]+[V^c(L,H)-V^{nc}(L,H)][W^c(L,L)-W^{nc}(L,L)]} = \hat{\alpha}^*.$$

(AA4). The coefficient of $r_{HH} \geq r_{LH}$ if and only if

$$\begin{aligned} &\gamma^*[V^c(L,L)-V^{nc}(L,L)][W^c(H,H)-W^{nc}(H,H)] \\ &-\alpha^*\gamma^*[V^c(L,H)-V^{nc}(L,H)][W^c(H,H)-W^{nc}(H,H)] \\ &-2\alpha^*[V^c(L,H)-V^{nc}(L,H)][W^c(L,H)-W^{nc}(L,H)] \geq 0. \end{aligned}$$

Now we need to go through the weary task of solving for the optimal second best mechanism for any permutation of relations between the coefficients. Let the number denote the condition: (AA1) means condition (AA1) holds, while -(AA1) means that condition (AA1) does not hold.
See figure 5 for the generic picture in the firms belief space (α^*, γ^*).

Case (AA1), (AA2):

$r_{LH} = 1$, and
$r_{LL} = 0$. Note that by assumption (A1) the coefficient of r_{LL} in the objective function is negative.
r_{HH} has to be chosen to satisfy IC(L):

$$r_{HH}^{SB} \leq \frac{\alpha^*[V^c(L,H)-V^{nc}(L,H)]-[V^c(L,L)-V^{nc}(L,L)]}{\alpha^*[V^c(L,H)-V^{nc}(L,H)]} = p_{R_5}(\alpha^*)$$

The regulator wants r_{HH} as large as possible since it has a positive coefficient in the expected welfare function: $r_{HH} = p_{R(5)}(\alpha^*)$.

Case (AA1), -(AA2):

$r_{LH} = 1$, and
$r_{HH} = 1$.
$r_{LL} = 1$ is the only possibility to satisfy IC(L).

Case -(AA1), (AA2), (AA3), (AA4) or -(AA1), (AA2), (AA3), -(AA4):

$r_{LL} = 0$.
By inspection of IC(L), the only solution is:
$r_{LH} = 0$, and
$r_{HH} = 0$.

Case -(AA1), -(AA2), -(AA3), (AA4):

$r_{HH} = 1$,
$r_{LH} = 1$, and
$r_{LL} = 1$ is the only possibility.

Case -(AA1), -(AA2), (AA3), (AA4):

$r_{HH} = 1$.

IC(L) requires $r_{LL}^{SB} \geq \frac{\alpha^*[V^{c}(L,H)-V^{nc}(L,H)]}{V^{c}(L,L)-V^{nc}(L,L)} = p_{R_{(3)}}(\alpha^*)$,

and thus $r_{LL} = p_{R(3)}$.

$r_{LH} = 0$, since any positive probability would tighten the constraint.

Case -(AA1), -(AA2), -(AA3), -(AA4):

$r_{LH} = 1$,

$r_{HH} = 1$,

$r_{LL} = 1$.

Case -(AA1), (AA2), -(AA3), -(AA4):

$r_{LH} = 1$.

IC(L) implies that $r_{LL}^{SB} = \frac{V^{c}(L,L)-V^{nc}(L,L)-\alpha^*[V^{c}(L,H)-V^{nc}(L,H)]}{V^{c}(L,L)-V^{nc}(L,L)} = p_{R(4)}(\alpha^*)$.

$r_{HH} = 0$, since any increase in r_{HH} would tighten the constraint even more and r_{LL} would have to be increased.

It is easy to check that conditions (AA2), (AA3) and (AA4) at equality are concurrent. Condition (AA4) is not a separating condition and therefore does not show up in Proposition 2.

<u>STEP 2:</u>

We still need to check if IC(H) is satisfied in all these cases.

In regions $R_{(1)}$ and $R_{(2)}$, IC(H) is trivially satisfied. The following lemma states the conditions in the other cases.

<u>Lemma 2:</u>

IC(H) holds in region $R_{(3)}$ if and only if

$$\forall (\alpha^*,\gamma^*) \in R_{(3)}: \gamma^* \geq \alpha^* \frac{[V^{c}(L,H)-V^{nc}(L,H)][V^{c}(H,L)-V^{nc}(H,L)]}{[V^{c}(L,L)-V^{nc}(L,L)][V^{c}(H,H)-V^{nc}(H,H)]}.$$

IC(H) holds in region $R_{(4)}$ if and only if $\forall (\alpha^*,\gamma^*) \in R_{(4)}: \gamma^* \leq \alpha^* \frac{[V^{c}(L,H)-V^{nc}(L,H)][V^{c}(H,L)-V^{nc}(H,L)]}{[V^{c}(L,L)-V^{nc}(L,L)][V^{c}(H,H)-V^{nc}(H,H)]}$.

IC(H) holds in region $R_{(5)}$ if and only if $\forall (\alpha^*,\gamma^*) \in R_{(5)}: \gamma^* \leq \alpha^* \frac{V^{c}(L,H)-V^{nc}(L,H)}{V^{c}(H,H)-V^{nc}(H,H)}$.

Proof: Straight forward. Just write out IC(H) in every case. ■

The conditions for regions $R_{(3)}$ and $R_{(4)}$ are exactly opposite. Note that if $IH_{(3)} \neq \phi$ then $IH_{(4)} = \phi$ and vice versa. IC(H) is violated in either $IH_{(3)}$ or $IH_{(4)}$. In region $R_{(3)}$ the high type is tempted to lie if he believes that his competitor is of the low type (if γ is high), in which case if he tells the truth, they will not be allowed to form a RJV. In region $R_{(4)}$ the high type would consider lying if he believes that his rival is also of the high type (if γ is low), since if the report is (H, H) they will not be allowed to form a RJV.

Lemma 3: If both IC(L) and IC(H) are binding then $r^{SB}_{\beta\beta} = 0 \quad \forall \beta_k \in \{L, H\}$ or $r^{SB}_{\beta\beta} = 1 \quad \forall \beta_k \in \{L, H\}$ in that region.

Proof:

IC(L) and IC(H) are both binding.
Solve IC(L) for r_{LL}:

$$r^{SB}_{LL} = \frac{V^c(L,L) - V^{nc}(L,L) - \alpha^*[V^c(L,H) - V^{nc}(L,H)]}{V^c(L,L) - V^{nc}(L,L)} r_{LH} + \frac{\alpha^*[V^c(L,H) - V^{nc}(L,H)]}{V^c(L,L) - V^{nc}(L,L)} r_{HH} .$$

Substitute into IC(H). IC(H) is binding if and only if

$$[\alpha^* \frac{[V^c(H,L) - V^{nc}(H,L)][V^c(L,H) - V^{nc}(L,H)]}{[V^c(L,L) - V^{nc}(L,L)][V^c(H,H) - V^{nc}(H,H)]} - \gamma^*][r_{HH} - r_{LH}] = 0 .$$

So either $r_{LH} = r_{HH}$ or $\alpha^* \frac{[V^c(H,L) - V^{nc}(H,L)][V^c(L,H) - V^{nc}(L,H)]}{[V^c(L,L) - V^{nc}(L,L)][V^c(H,H) - V^{nc}(H,H)]} = \gamma^*$.
The second condition exactly indicates the border of the region where IC(H) will be violated (Lemma 2).
Substituting $r_{LH} = r_{HH}$ into the formula for r_{LL} gives us $r_{LL} = r_{LH} = r_{HH}$.

■

In the regions where both IC constraints are binding, we have to compare the policy where no RJV's are allowed with the case of always allowing a RJV which is equivalent to checking :
$\text{sign}[p_{LL}[W^c(L, L) - W^{nc}(L, L)] + 2p_{LH}[W^c(L, H) - W^{nc}(L, H)] + p_{HH}[W^c(H, H) - W^{nc}(H, H)]] = \text{sign } U$.
If U is positive in that specific region, then RJV's should always be allowed (see proposition).

In the statement of the Proposition 2 the regions $IH_{(x)}$ coincide with regions where IC(H) is violated, while in the regions $R_{(x)} \setminus IH_{(x)}$ only IC(L) is binding. ■

Proof of Proposition 3
A simple exercise in differentiation.
Note that ρ and θ only enter these probabilities through α^* and that

$$\frac{\partial \alpha^*}{\partial \rho} = \frac{1-\theta}{[\rho+(1-\rho)\theta]^2} < 0$$

$$\frac{\partial \alpha^*}{\partial \theta} = \frac{1-\rho}{[\rho+(1-\rho)\theta]^2} < 0$$

and

$$\frac{\partial p_i}{\partial \rho} = \frac{\partial p_i}{\partial \alpha^*} \frac{\partial \alpha^*}{\partial \rho}$$

$$\frac{\partial p_i}{\partial \theta} = \frac{\partial p_i}{\partial \alpha^*} \frac{\partial \alpha^*}{\partial \theta}$$

while

$$\frac{\partial p_{R_3}}{\partial \alpha^*} > 0$$

$$\frac{\partial p_{R_4}}{\partial \alpha^*} < 0$$

$$\frac{\partial p_{R_5}}{\partial \alpha^*} > 0$$

This gives us the desired results. ■

Proof of Proposition 4

See proof of proposition 5.

Proof of Proposition 5

We take the same approach as in the proof of Proposition 2. In STEP 1 the model is solved while assuming that only IC(L) is binding, while in STEP 2 we check if and when IC(H) is satisfied.

STEP 1:

Subsidies decrease the expected welfare. Setting S_{HL} and S_{HH} equal to zero does not hurt the IC(L). There is now one more relative coefficient to compare: the coefficient on the expected subsidy of the firm with low spillover. The other relative coefficients are the same as in proposition 1.

The coefficient on $[S_{LL} + \alpha^* S_{LH}]$ is $2\lambda p_{LL}$.

The comparisons between r_{LL}, r_{LH} and r_{HH} in proposition 2 are still valid. We just compare them with the new coefficient.

(AA1'). The coefficient of $r_{LL} \geq$ coefficient on subsidies if and only if

$$\hat{\lambda} \leq \frac{W^{F}(L,L)-W^{NF}(L,L)}{2[V^{F}(L,L)-V^{NF}(L,L)]} = \lambda^*.$$

(AA2'). The coefficient of $r_{LH} \geq$ coefficient on subsidies if and only if

$$\alpha^* \geq \frac{\lambda[V^{F}(L,L)-V^{NF}(L,L)]}{W^{F}(L,H)-W^{NF}(L,H)+\lambda[V^{F}(L,H)-V^{NF}(L,H)]} = \hat{\alpha}^*(\hat{\lambda}).$$

(AA3'). The coefficient of $r_{HH} \geq$ coefficient on subsidies if and only if

$$\gamma^* \geq \frac{2\lambda[V^{F}(L,H)-V^{NF}(L,H)]}{W^{F}(H,H)-W^{NF}(H,H)} = \hat{\gamma}^*(\lambda).$$

It is clear that if the relative coefficient of subsidies is larger than any of the other coefficients, the regulator will set subsidies to zero since they would decrease expected welfare too much. However, if the coefficient of subsidies is larger than the coefficient of r_{LL}, thus if $\lambda \geq \lambda^*$, then before setting r_{LL} as small as possible, subsidies will be set as small as possible, still satisfying IC(L). We are now back in the no-subsidy case. This proves proposition 4.

Again we are left with the task of checking all cases that are permutations of the conditions (AA1)-(AA4), (AA1')-(AA3') holding or not in the case that (AA1') holds. However, several cases will give the same optimal second best mechanism.
See Figure 6 for the generic picture in the firms belief space (α^*, γ^*).The dotted lines are the extra conditions for the subsidy case. Only the regions that differ w.r.t. Figure 5 are labeled.

Cases: -(AA1), -(AA2), (AA3), (AA4), (AA2'), (AA3')
-(AA1), -(AA2), -(AA3), -(AA4), (AA2'), (AA3')
-(AA1), (AA2), (AA3), (AA4), (AA2'), (AA3')
-(AA1), (AA2), -(AA3), -(AA4), (AA2'), (AA3')
-(AA1), (AA2), (AA3), -(AA4), (AA2'), (AA3')
(AA1), -(AA2), (AA2'), (AA3')
-(AA1), -(AA2), -(AA3), (AA4), (AA2'), (AA3')
(AA1), (AA2), (AA2'), (AA3')

$r_{LL} = 0$,
$r_{LH} = 1$, and
$r_{HH} = 1$.
The subsidies are derived from the IC(L) constraint:

$$S_{LL} + \alpha^* S_{LH} = V^c(L, L) - V^{nc}(L, L).$$

Cases: -(AA1), -(AA2), (AA3), (AA4), -(AA2'), (AA3')
-(AA1), (AA2), (AA3), (AA4), -(AA2'), (AA3')

$r_{LL} = 0$, and
$r_{HH} = 1$.
Subsidies are minimized such that the IC(L) holds:

$$S_{LL} + \alpha^* S_{LH} = \alpha^*[V^c(L, H) - V^{nc}(L, H)].$$

The remaining probability can only be set to zero: $r_{LH} = 0$.

Cases: -(AA1), (AA2), (AA3), -(AA4), (AA2'), -(AA3')
-(AA1), (AA2), -(AA3), -(AA4), (AA2'), -(AA3')

$r_{LL} = 0$, and
$r_{LH} = 1$.
Subsidies are minimized such that IC(L) holds:

$$S_{LL} + \alpha^* S_{LH} = V^c(L, L) - V^{nc}(L, L) - \alpha^*[V^c(L, H) - V^{nc}(L, H)].$$

The remaining probability is set to zero: $r_{HH} = 0$.

Case: (AA1), (AA2), (AA2'), -(AA3')

$r_{LL} = 0$, and
$r_{LH} = 1$.
Subsidies are set as small as possible: $S_{LL} + \alpha^* S_{LH} = 0$ in this case.
r_{HH} has to be chosen as large as possible and has to satisfy IC(L):

$$r_{HH}^{SB} = \frac{\alpha^*[V^c(L,H) - V^{nc}(L,H)] - [V^c(L,L) - V^{nc}(L,L)]}{\alpha^*[V^c(L,H) - V^{nc}(L,H)]} = p_{R_5}(\alpha^*) \cdot$$

Cases: -(AA1), (AA2), (AA3), (AA4), -(AA2'), -(AA3')
-(AA1), (AA2), (AA3), -(AA4), -(AA2'), -(AA3')

$r_{LL} = 0$.
Subsidies are now minimized: $S_{LL} + \alpha^* S_{LH} = 0$.
The only probabilities for r_{LH} and r_{HH} that can still satisfy IC(L) are:
$r_{LH} = 0$, and
$r_{HH} = 0$.

STEP 2:
Again we need to check for conditions when IC(H) is satisfied.
A straightforward exercise in plugging the results of different regions into IC(H) gives us the following conditions to be satisfied:

(AA5). IC(H) holds in $R\lambda_{(1)}$ if and only if
$$(\gamma^* - \alpha^*)S_{LH} - [V^c(H, L) - V^{nc}(H, L)] + V^c(L, L) - V^{nc}(L, L) \leq 0.$$

(AA6). IC(H) holds in $R\lambda_{(3)}$ if and only if
$$(\gamma^* - \alpha^*)S_{LH} + \alpha^*[V^c(L, H) - V^{nc}(L, H)] - \gamma^*[V^c(H, H) - V^{nc}(H, H)] \leq 0.$$

(AA7). IC(H) holds in $R\lambda_{(4)}$ if and only if
$$(\gamma^* - \alpha^*)S_{LH} + \gamma^*[V^c(H, H) - V^{nc}(H, H)] - \alpha^*[V^c(L, H) - V^{nc}(L, H)] + V^c(L, L) - V^{nc}(L, L) - V^c(H, L) + V^{nc}(H, L) \leq 0.$$

To simplify the exposition, we make the following assumptions:

A5: $\hat{\gamma}^* \leq \dfrac{V^c(L,L) - V^{nc}(L,L)}{V^c(H,H) - V^{nc}(H,H)}$,

A6: $V^c(H, L) - V^{nc}(H, L) \geq V^c(L, L) - V^{nc}(L, L)$,

A7: $V^c(H, H) - V^{nc}(H, H) \geq V^c(L, H) - V^{nc}(L, H)$,

A8: $\hat{\gamma}^* \leq \dfrac{[V^c(H,L) - V^{nc}(H,L)] - [V^c(L,L) - V^{nc}(L,L)]}{[V^c(H,H) - V^{nc}(H,H)] - [V^c(L,H) - V^{nc}(L,H)]}$, A8': $\hat{\gamma}^*(\lambda) \leq \hat{\alpha}^*(\lambda)$.

Assumption (A5) comes straight from Lemma 2 and guarantees that IC(H) is not binding in region $R_{(5)}$. Assumption (A6) states that the profit gains from forming a RJV for the high type are larger than that of a low type when the rival is of the low type and (A7) is a similar statement if the rival is a high type. Both (A6) and (A7) imply that regardless of the competitor's type, the gains from R&D cooperation for the high spillover type are larger than those of a low spillover type. The rival of a high spillover firm will reduce its R&D expenditures significantly, since he loses everything to the high spillover firm. By forming a RJV, this negative externality is internalized and R&D investments increase. This benefits the high spillover firm in particular. Assumptions (A8) and (A8') are made to simplify the exposition (see Appendix B). Since $\hat{\gamma}^*(\lambda) \leq \hat{\gamma}^*$, assumption (A8) implies that $\hat{\gamma}^*(\lambda)$ is low. A firm with a high spillover will place high probability on the event that his rival is of the low type (γ is high).

Lemma 4: If (A1)-(A8') hold, then IC(H) is always satisfied.

Proof:

* Set $S_{LH} = 0$.
(AA5) is immediately satisfied if (A6) holds.

* Set $S_{LH} = V^c(L, H) - V^{nc}(L, H)$.
(AA6) is immediately satisfied if (A7) holds.

* Set $S_{LH} = 0$.
From (A8') we know that $\alpha^* \geq \gamma^*$ for all (α^*, γ^*) in region (4).

(AA7) $\leq$
$\gamma^*[V^c(H, H) - V^{nc}(H, H)] - \gamma^*[V^c(L, H) - V^{nc}(L, H)] + V^c(L, L) - V^{nc}(L, L) - V^c(H, L) + V^{nc}(H, L)$,

(A8) insures that this expression is still less than zero.

* If (A5) holds, then IC(H) is satisfied in region 5, from Lemma 2. ■

With the assumptions (A5)-(A8') made in STEP 2, only IC(L) is binding and the results of STEP 1 determine the second-best policy.

■

Appendix B

To make things as tractable as possible, we focus on a simple cost reducing investment game proposed by d'Aspremont and Jacquemin (1988).
The game firms play is a two stage game. In the first stage they make R&D investment decisions to reduce their marginal costs of production in the second stage. In the second stage firms compete in quantities in the output market. Spillovers through which knowledge (part of the firms investment) is also acquired by the rival firm, occur in the first stage. After the first stage firms observe each others R&D levels.[16]
Let x_i be firm i's first stage R&D investment and q_i its second stage market output. Let MC_i be firm i's marginal cost of production:
$MC_i = c - x_i - \beta_j x_j$ where $\beta_i = L = 0$ or $\beta_i = H = 1$. Firms products are homogeneous with demand $p = a - Q$, where $Q = q_1 + q_2$ and $a > c$.
We now append a stage to the game before the firms make any decisions. In this stage the regulator sets up the mechanism where it allows RJV's or not depending on the firms reports and can give a lump sum subsidy.
Profits and welfare will depend on the institutional mechanism set up by the regulator.
To simplify notation we will index all functions by:
- nc: when firms act non cooperatively in both stages.
- c: when a RJV is formed.[17]

To obtain a subgame perfect equilibrium, we solve the game backwards. Firms always act non cooperatively (Nash-Cournot) in the output market (suppose this is enforced by antitrust legislation). We can solve for the output levels as a function of R&D investment levels in the first stage:

$$q_i(x_i, x_j;\ \beta_i,\ \beta_j) = Z + A_i x_i + B_j x_j \qquad \text{where} \qquad Z = (a-c)/3,\quad A_i = (2-\beta_j)/3,\quad B_j = (2\beta_j - 1)/3$$

note that $A_i > 0 \ \forall\ \beta_i$ and $B_i < 0$ if $\beta_i = 0$, $B_i > 0$ if $\beta_i = 1$.
In the previous stage firms decide on R&D investment. Note that we assumed that at the time that the firms make their R&D and output decisions they have perfect information about the state of nature. The regulator can influence this decision by its R&D policy schedule that is set up in a stage before the firms play their two stage game.

Profits reduced to the R&D stage are:

$$V_i^k(x_i, x_j;\ \beta_i,\ \beta_j) = [q_i(x_i, x_j;\ \beta_i,\ \beta_j)]^2 - (\Gamma/2)(x_i)^2 \text{ where } x_i = x_i^k(\beta_i,\ \beta_j) \text{ and } k = nc \text{ or } c$$

where $(\Gamma/2)(x_i)^2$ is the cost function for R&D investments accounting for decreasing returns to scale in R&D. Γ is an efficiency parameter: the lower Γ, the more efficient the firm in its R&D investments.

The equilibrium R&D levels for the different cases are:

Firms compete in R&D:

$$x_i^{nc}(\beta_i,\ \beta_j) = [2ZA_i(\Gamma - 2A_j^2 + 2A_jB_i)]/N$$
$$\text{where } N = (\Gamma - 2A_i^2)(\Gamma - 2A_j^2) - (2A_iB_j)(2A_jB_i)$$

Firms form a RJV:

$$x_i^c(\beta_i,\ \beta_j) = 2Z[(A_j+B_i)(2A_1B_1 + 2A_2B_2) + (A_i+B_j)(\Gamma - 2A_j^2 - 2B_i^2)]/M$$
$$\text{where } M = (\Gamma - 2B_1^2 - 2A_2^2)(\Gamma - 2A_1^2 - 2B_2^2) - (2A_1B_1 + 2A_2B_2)^2$$

We assume that all output levels are non negative, the second order conditions are satisfied as well as the stability conditions on the problem (Seade (1980), Henriques (1990), d'Aspremont and Jacquemin (1990), De Bondt and Henriques (1992), De Bondt, Slaets and Cassiman (1992)). Basically this will put lower bounds on the R&D efficiency parameter Γ: Γ must be "sufficiently" large.
From these conditions we derive that $\Gamma > \underline{\Gamma} = 4/3$.[18]

The welfare function (consumer (CS^k) plus producer surplus ($V_1^k + V_2^k$)) is:

$$W^k(\beta_i,\ \beta_j) = (q_1+q_2)^2/2 + (q_1^2+q_2^2) - \Gamma/2\ (x_1^2+x_2^2) \qquad \text{where } k = nc \text{ or } c.$$

Now we are able to calculate the reduced form profit and welfare functions gross of subsidies for all states for all possible government R&D policies under perfect information. These are the objects we care about in the paper.

$$W^{nc}(L,L) = \frac{4(a-c)^2\,\Gamma}{9\Gamma-4} \qquad W^{c}(L,L) = \frac{4(a-c)^2(9\Gamma-1)\Gamma}{(9\Gamma-2)^2}$$

$$W^{nc}(L,H) = \frac{2(a-c)^2(162\Gamma^3-261\Gamma^2+132\Gamma-16)\Gamma}{(9\Gamma-4)^2(3\Gamma-2)^2} \qquad W^{c}(L,H) = \frac{2(a-c)^2(\Gamma-1)(18\Gamma^2-23\Gamma+4)\Gamma}{(9\Gamma^2-14\Gamma+4)^2}$$

$$W^{nc}(H,H) = \frac{4(a-c)^2(9\Gamma-1)\Gamma}{(9\Gamma-4)^2} \qquad W^{c}(H,H) = \frac{4(a-c)^2(9\Gamma-4)\Gamma}{(9\Gamma-8)^2}$$

$$V^{nc}(L,L) = \frac{(a-c)^2(9\Gamma-8)\Gamma}{(9\Gamma-4)^2} \qquad V^{c}(L,L) = \frac{(a-c)^2\,\Gamma}{9\Gamma-2}$$

$$V^{nc}(L,H) = \frac{(a-c)^2(3\Gamma-4)^2(9\Gamma-2)\Gamma}{(9\Gamma-4)^2(3\Gamma-2)^2} \qquad V^{c}(L,H) = \frac{(a-c)^2(\Gamma-2)\Gamma}{9\Gamma^2-14\Gamma+4}$$

$$V^{nc}(H,L) = \frac{9(a-c)^2(9\Gamma-8)\Gamma^2}{(9\Gamma-4)^2(3\Gamma-2)^2} \qquad V^{c}(H,L) = \frac{(a-c)^2\,\Gamma^2}{9\Gamma^2-14\Gamma+4}$$

$$V^{nc}(H,H) = \frac{(a-c)^2(9\Gamma-2)\Gamma}{(9\Gamma-4)^2} \qquad V^{c}(H,H) = \frac{(a-c)^2\Gamma}{9\Gamma-8}$$

Proposition (B1): There exists a Γ^* such that for all $\Gamma > \max\{\Gamma^*, \underline{\Gamma}\}$ the assumptions A1-A4 are satisfied in this model.

proof: Note that all reduced form profit and welfare functions are a function of Γ and $(a-c)^2$ and are separable in these terms. To check the assumptions it is sufficient to check the largest root $\Gamma^{(i)}$ of these expressions and check the sign of these expressions for larger Γ. This can be done fairly easy with a program such as mathematica. I will only explicit the condition such that the assumption holds.[19]

(A1) holds for all $\Gamma > \max\{4/9, \underline{\Gamma}\} = \underline{\Gamma}$
(A2) holds for all $\Gamma > \max\{1.11496, \underline{\Gamma}\} = \underline{\Gamma}$
(A3) holds for all $\Gamma > \max\{32/45, \underline{\Gamma}\} = \underline{\Gamma}$

(A4) holds for all Γ that satisfy non negativity, concavity since we assume that the firms forming a RJV will maximize joint profits. This implies that $\text{Max}_{x1,\,x2}\,(V_1 + V_2) \geq \text{Max}_{x1}\,V_1 + \text{Max}_{x2}\,V_2$. Allowing for transfers and the fact that firms can not be forced to form a joint venture insures that (A4) holds.
We could also focus on a particular split of the joint profits namely the one where no transfers are involved, each firm gets the profits according to its production when individual R&D levels are chosen to maximize joint profits. Again we can derive the conditions on Γ for (A4) to hold:

in state (L, L) (A4) holds if $\Gamma > \max\{2/9, \underline{\Gamma}\} = \underline{\Gamma}$
in state (L, H) (A4) holds if $\Gamma > \max\{3.3611, \underline{\Gamma}\} = 3.3611$!!
in state (H, L) (A4) holds if $\Gamma > \max\{0.84818, \underline{\Gamma}\} = \underline{\Gamma}$
in state (H, H) (A4) holds if $\Gamma > \max\{8/9, \underline{\Gamma}\} = \underline{\Gamma}$

Let $\Gamma^* = 4/9$ in the general case or let $\Gamma^* = 3.3611$ in the specific RJV profit sharing case.

■

Note that in the general case $\Gamma^* < \underline{\Gamma}$ such that all the assumptions are satisfied when non-negativity, concavity and stability are assumed on the whole model.

<u>Proposition (B2)</u>: For all $\Gamma > \underline{\Gamma}$ the assumptions A5-A8' are satisfied in this model.

proof: (A5) holds for all $\Gamma > \max\{1.0583, \underline{\Gamma}\} = \underline{\Gamma}$
(A6) and (A7) hold for all $\Gamma > \max\{0.840173, \underline{\Gamma}\} = \underline{\Gamma}$
(A8) holds for all $\Gamma > \max\{1.14653, \underline{\Gamma}\} = \underline{\Gamma}$
(A8') holds for all $\Gamma > \max\{1.08495, \underline{\Gamma}\} = \underline{\Gamma}$ ■

We have shown that all assumptions made in the general model are satisfied in this simplified model. We use the simplified model to guide our intuitions for the general model.

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Notes

1. However, see Levin and Reiss (1988), Cohen and Levinthal (1989) and Papaconstantinou (1990) for a different result.

2. We will consider the government and the regulator as the same player throughout this paper.

3. Mechanism design in a regulation context with more than one firm has been a fruitful new direction in the regulation literature (Baron (1989), Anton and Yao (1989), Auriol and Laffont (1992), Demski and Sappington (1984), McGuire and Riordan (1991), Olsen (1993), Wolinsky (1993)).

4. Forming a RJV can be thought of as maximizing joint profits in the R&D stage. No efficiency gains in R&D are assumed and no new entity is necessarily created by this agreement. Fusfeld and Haklish (1985) report that 1/3 of cooperative research is conducted at in-house facilities of the cooperating entities. They also quote John Young, president of Hewlett-Packard on the value of cooperative R&D: "it will enable U.S. electronic companies to discuss and coordinate our research objectives and to gain leverage on our expenditures". Firms thus contract on the amount of R&D they will perform, which is consistent with our definition of a RJV. See also Audretsch (1989) and Odagiri (1986) for similar examples of cooperative research in Japan. A possible motivation of this paper then becomes: are there situations that government would want to promote joint profit maximization in the R&D stage even without any efficiency gains except for internalizing the effect of spillovers on R&D investments and profits.

5. This of course is only one of the possible games played. If the firms know the state of the world before reporting, the government can illicit truthful revelation by having both firms report the state of the world instead of only their own spillover. If the reports do not coincide, both firms are punished severely. In the case that the firms do not learn the true state of the world, the most general game would involve the whole communication game: the regulator screens the firms while the firms signal their types to each other. The firms will update their beliefs according to the reports of their rival. This will complicate matters substantially. Truthful revelation is not necessarily an equilibrium of this general game since the report of the firms serves as an announcement to both the government and the firm's rival.

6. We only consider non-negative subsidies for two reasons: first, an institution responsible for R&D policy usually does not have the authority to tax R&D and second, when considering a cost of public funds it might lead to a perverse effect of taxing the firms to make money since the cost of funds now adds to welfare.

7. In Appendix B it is shown that these assumptions are consistent with existing models of R&D competition or cooperation with appropriability problems.

8. Note that because of the duopoly setup the RJV solves both the public good problem and the externality caused by the spillover. If there are more than two firms in the industry, the regulator could also use the maximal number of firms allowed into the RJV as a policy instrument. Tentative results seem to suggest that under full information the regulator prefers no RJV in the case of low spillovers compared to an industry wide RJV in the case of high spillovers. The firms, however, will always prefer some intermediate size of the RJV (De Bondt and Wu (1994)).

9. The reverse inequality leads to qualitatively similar conclusions.

10. We will not consider potential incentive problems between the partners of a RJV (see Veugelers and Kesteloot (1993)).

11. The relation between the government beliefs and these transformed probabilities is:

$$p_{LL} = \frac{1}{1+2\alpha^*+\alpha^*\gamma^*}$$
$$p_{LH} = \frac{\alpha^*}{1+2\alpha^*+\alpha^*\gamma^*}$$
$$p_{HH} = \frac{\alpha^*\gamma^*}{1+2\alpha^*+\alpha^*\gamma^*}$$

12. Note the following degeneracies: $\rho = -1 \Rightarrow p_{LH} = p_{HL} = .5$,
$\theta = 1 \Rightarrow p_{LL} = 1$,
$\theta = 0 \Rightarrow p_{HH} = 1$.

13. $\alpha = \rho + (1-\rho)\theta$ and $\gamma = (1-\rho)\theta$ or $\rho = \alpha-\gamma$ and $\theta = \gamma / (1-\alpha+\gamma)$.
$p_{LL} = \theta[\theta+\rho(1-\theta)]$, $p_{LH} = \theta(1-\theta)(1-\rho)$ and $p_{HH} = [1-(1-\rho)\theta](1-\theta)$.

14. $U(\rho, \theta) = 0$, sign $(d\theta/d\rho)$ depends on the relative magnitudes of $[W^c(L, L) - W^{nc}(L, L)]$, $[W^c(L, H) - W^{nc}(L, H)]$ and $[W^c(H, H) - W^{nc}(H, H)]$, in Figure 1 it is slightly increasing.

15. In figure 1 we assume $\frac{[V^c(L,H)-V^{nc}(L,H)][V^c(H,L)-V^{nc}(H,L)]}{[V^c(L,L)-V^{nc}(L,L)][V^c(H,H)-V^{nc}(H,H)]} \geq 1$ in region $IH_{(3)}$, (A5) holds (see Appendix A) and $\hat{\gamma}^* \leq \hat{\alpha}^*$.

16. This assumption is to allow for strategic interactions w.r.t. R&D (De Bondt and Veugelers (1991)).

17. Forming a RJV in this model stands for maximizing joint profits in the R&D stage. No efficiency gains in R&D are assumed. No new entity is necessarily created by this agreement. See also footnote 5.

18. The exact conditions and calculations are available upon request.

19. The full calculations are available but not very informative.

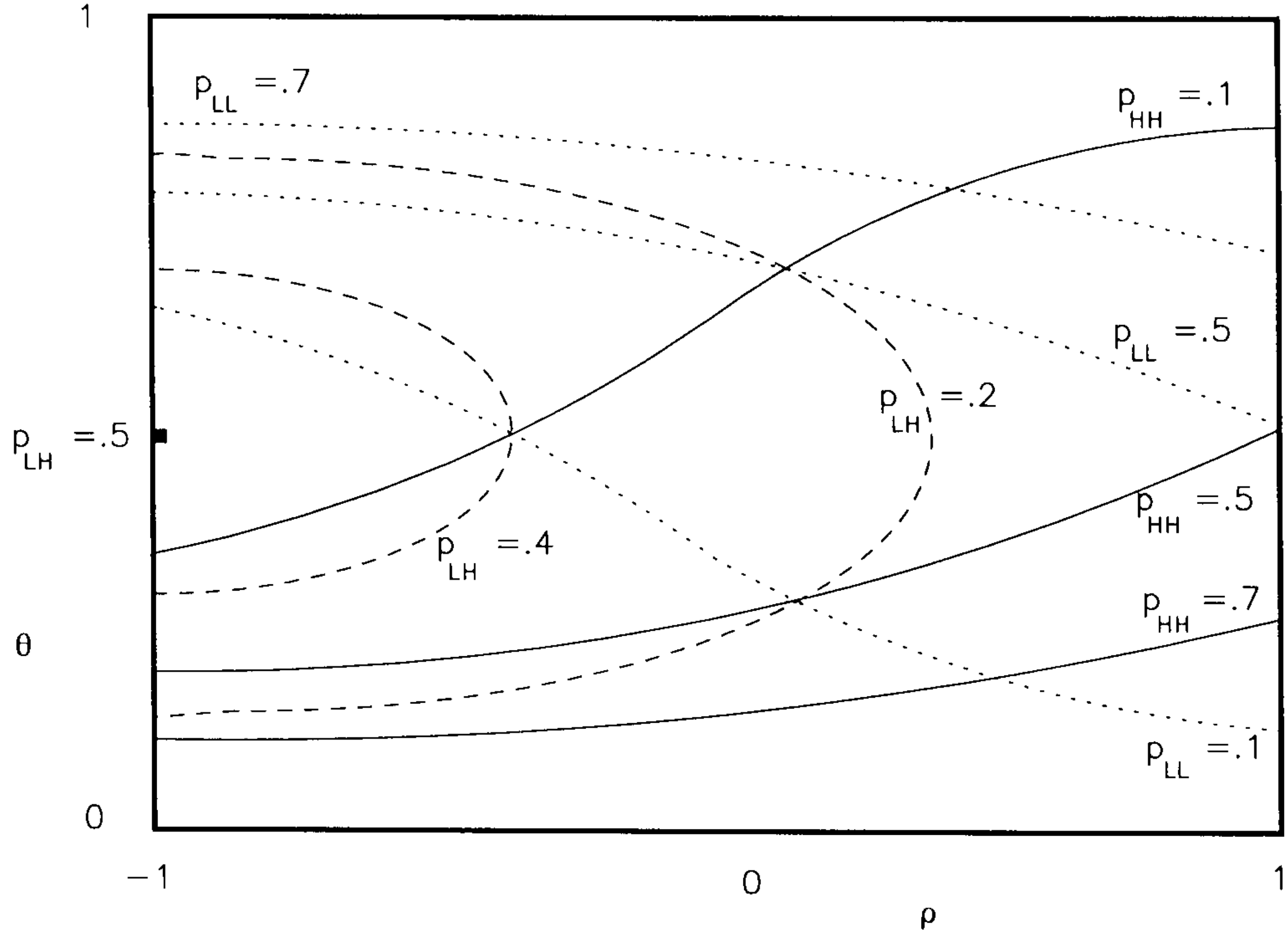

Figure 1: Iso-Probability Lines of Government Beliefs in Terms of Correlation of Types and Marginal Probability of Low Type.

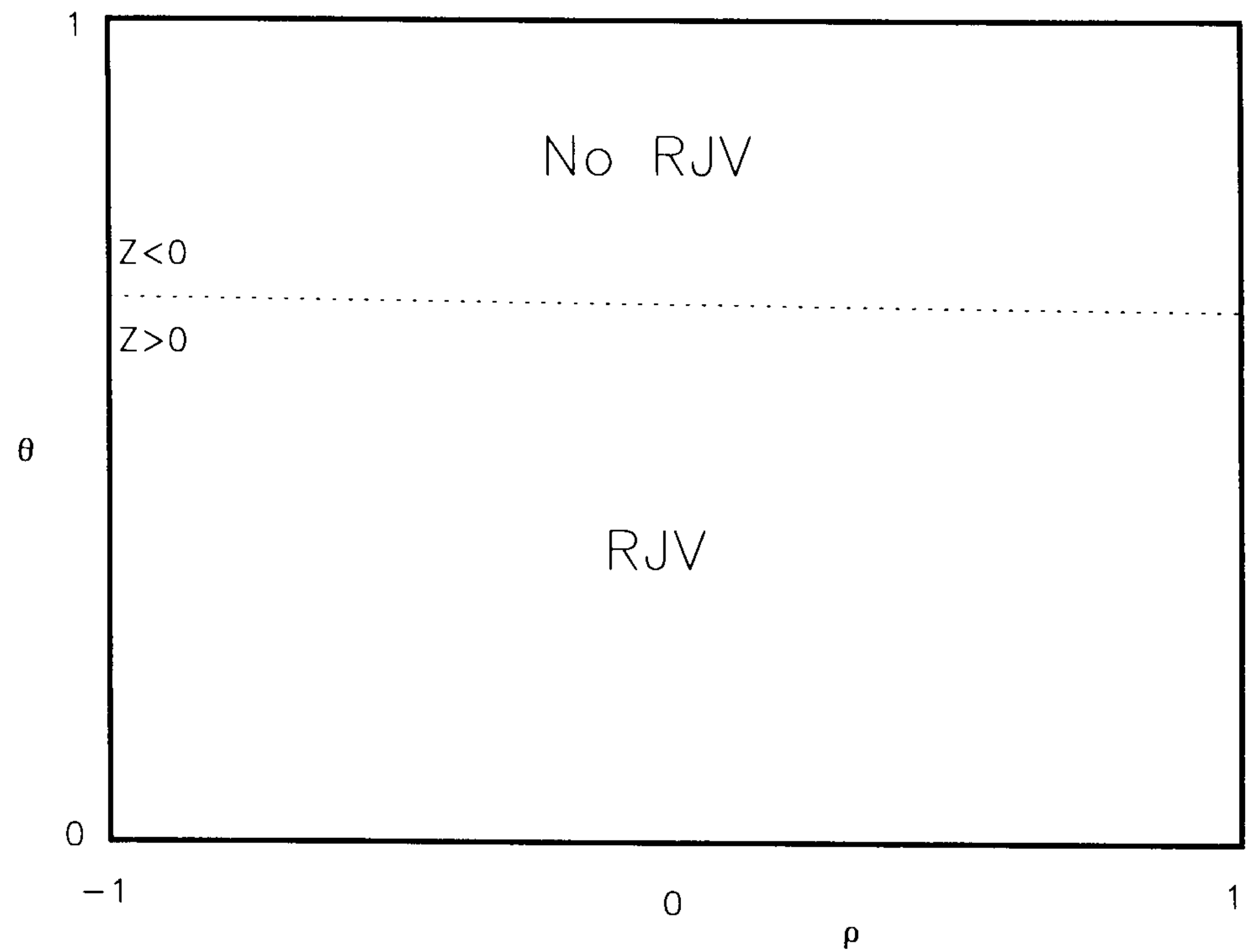

Figure 2: Optimal R&D Policy, Ignoring the Firms' Information.

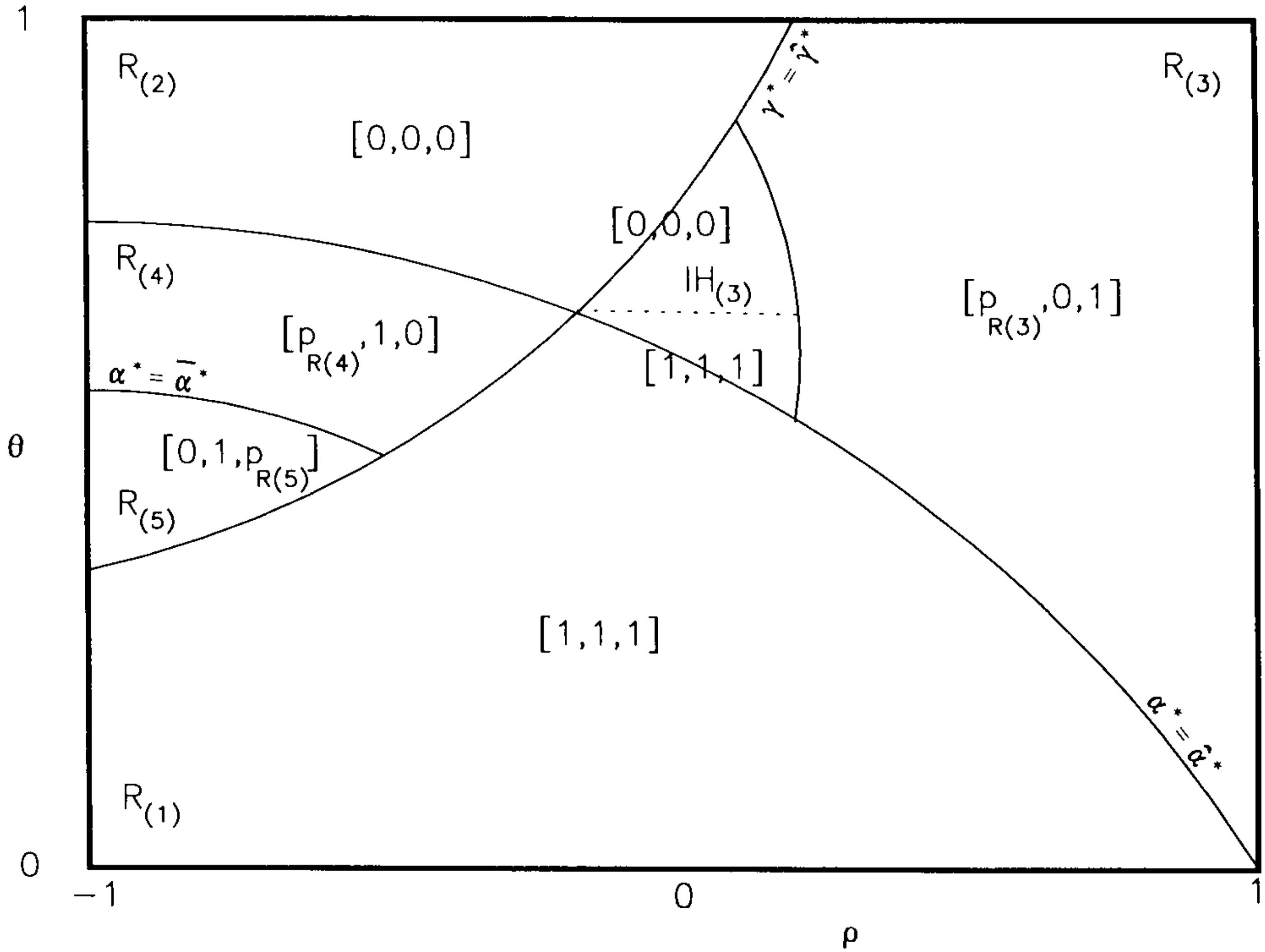

Figure 3: Second-Best R&D Policy without Subsidies in Terms of Correlation of Types and Marginal Probability of Low Type.

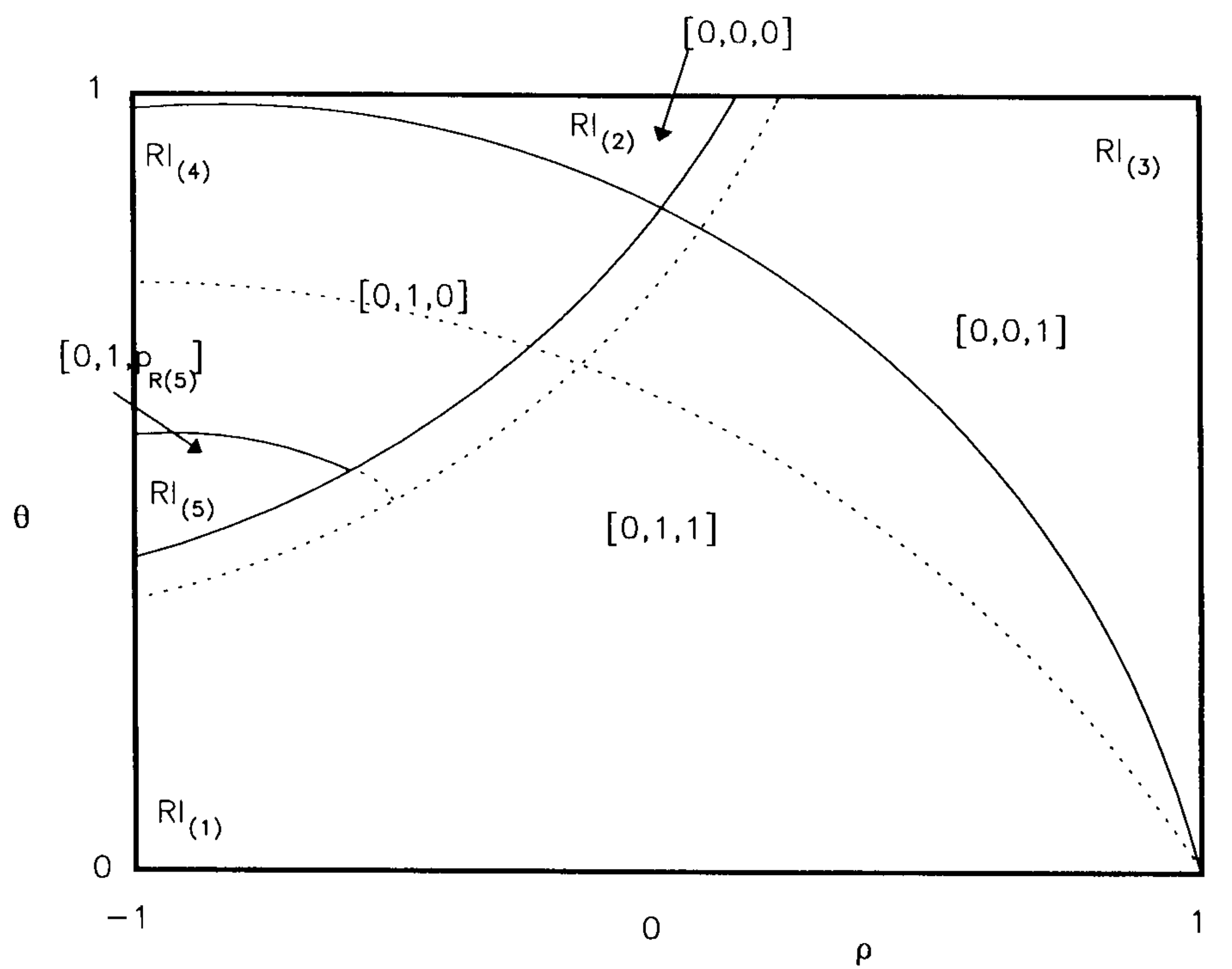

Figure 4: Second-Best R&D Policy with Subsidies and Low Cost of Public Funds in Terms of Correlation of Types and Marginal Probability of Low Type.

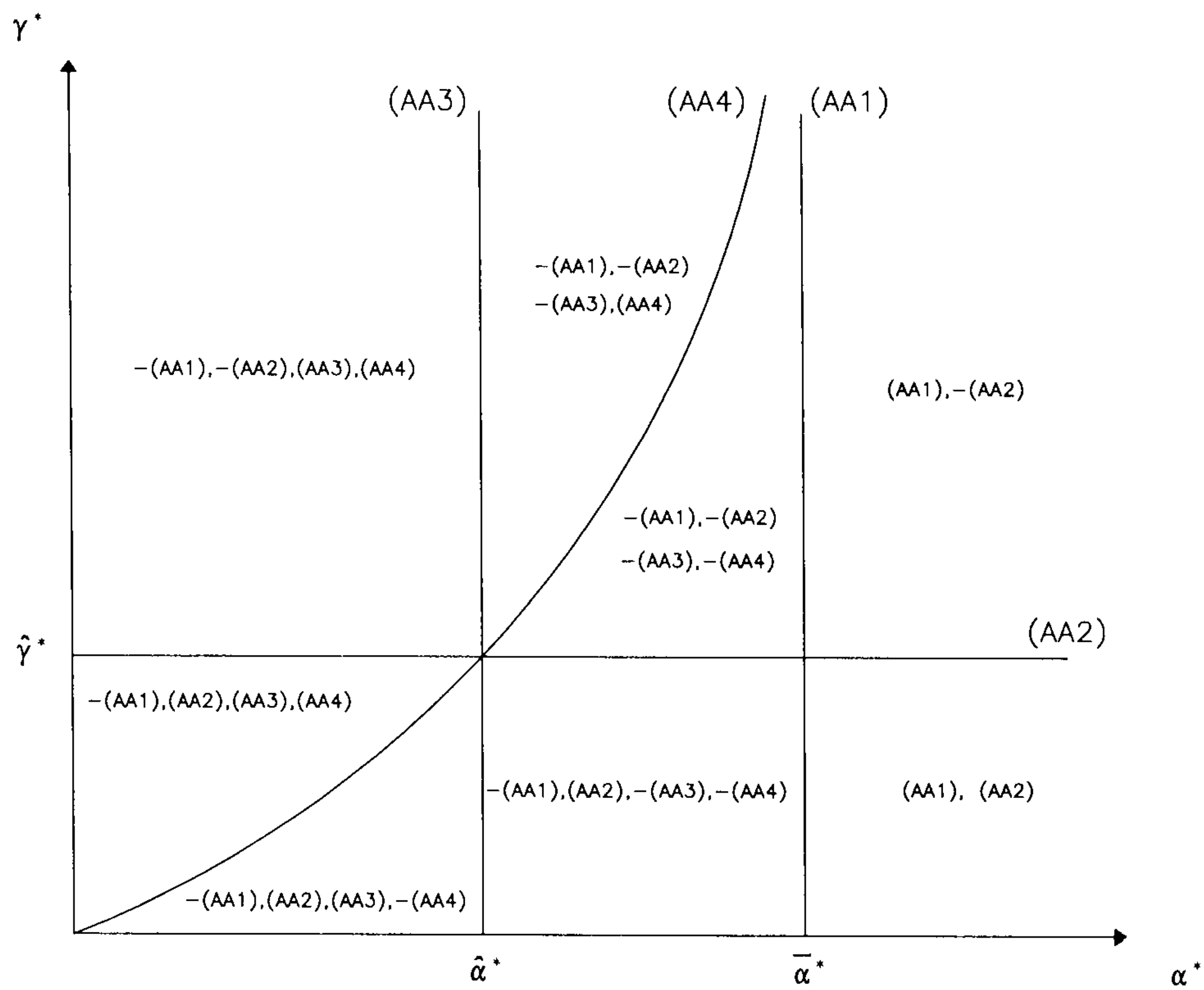

Figure 5:Regions relevant for Second-Best R&D Policy without Subsidies in Belief Space (α^*, γ^*) of Firms. (Proposition 2).

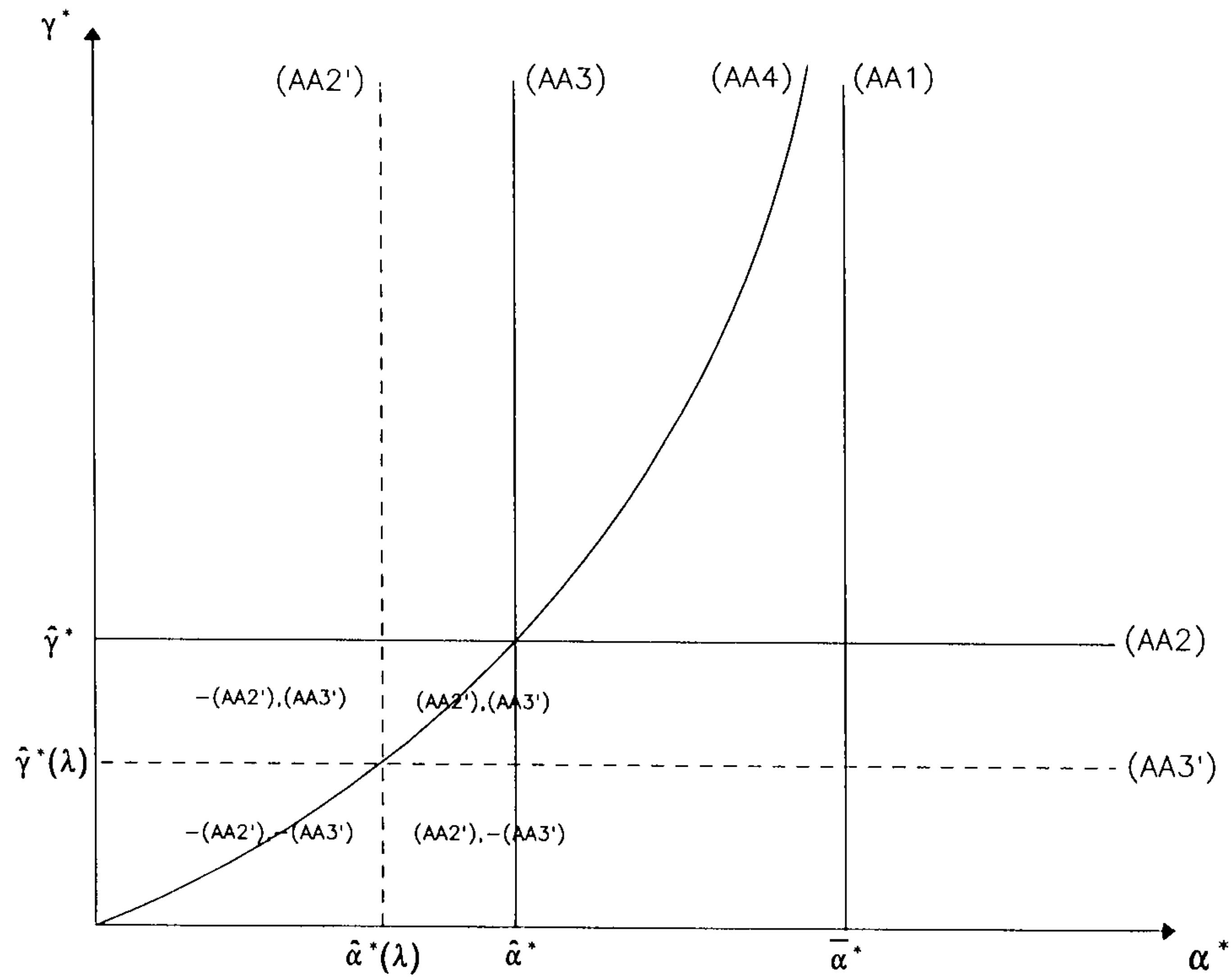

Figure 6:Regions relevant for Second-Best R&D Policy with Subsidies in Belief Space (α^*, γ^*) of Firms. (Proposition 5).