Pooling of risky assets and the intensity of cooperation in R&D

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Abstract

In the case considered, risk averse …rms agree in advance to share R&D results but not R&D costs. Real R&D expenditure is unobservable, which creates a moral hazard problem. The …rms contract at the …rst stage on the intensity of cooperation and at the second stage on the research e¤ort. Moral hazard weakens the …rms' motives to invest in R&D during cooperation. But diversifying the portfolio of R&D projects through cooperation increases …rms' utility. It turns out that in the absence of monitoring, the …rms choose either high e¤ort and low intensity of cooperation or, alternatively, low e¤ort and maximal intensity of cooperation. If a …rm can monitor a partner's real R&D e¤ort through a signal, moral hazard can weaken to an extent that risk averse and independent …rms choose high e¤ort and maximal intensity of cooperation, even if they were indi¤erent between high e¤ort and low e¤ort under isolation.

keywords: R&D expenditure, moral hazard, diversi…cation

JEL codes: O31, O32,O38

1 Introduction and summary of the results[1]

We examine cooperation in R&D. In the literature there are various reasons which explain cooperation in R&D. However, if …rms are competitiors, such conditions are not easily met that are su¢cient for cooperation on R&D.

[1] This paper will be presented in EARIE 2000 (in Lausanne). This paper is a part of a larger governmental evaluation programme coordinated by the Finnish National Fund for Research and Development.

According to D'Aspremont and Jacquemin (1988), and Katz and Ordover (1990), spillovers outside can be reduced, if R&D results are shared between two …rms. The need to eliminate duplication of R&D e¤ort may also motivate the …rms to coordinate their R&D investments (see Katz and Ordover (1990) and Kamien et al. (1992)).

But cooperation can also be motivated, if the e¤orts are complementary either in research (see e.g. Veugelers and Kesteloot, 1994) or in the product market. Katz and Ordover (1990) have noticed that R&D e¤ort may become complementary when one …rm learns from another's success.

Cooperation which leads to sharing of R&D results leads almost inevitably to intensi…ed competition in the product market, which weakens the incentives to share R&D results. This is stressed by almost all authors who have studied cooperation in R&D (see D'Aspremont and Jacquemin (1988), Katz and Ordover (1990), Kamien et al. (1992), Katsoulacost and Ulph (1998) and Stenbacka and Tombak (1998)). However, if cooperating …rms belong to complementary industries, this e¤ect vanishes (see. e.g. Katsoulacost and Ulph (1998)).

D'Aspremont and Jacquemin in 1988 and since then many authors have noticed that insofar as R&D results only are shared, and the costs of exerting R&D e¤ort are not, there arises a free-rider problem. According to D'Aspremont and Jacquemin (1988) the possibility to cooperate on R&D would increase R&D expenditure, if spillovers outside are large enough. As Kamien et al. (1992) have shown, the creation of a research joint venture (RJV) that cooperates in its R&D decisions and maximizes the joint pro…t solves the problems of free-riding. Basically, the existence of moral hazard depends on the observability of real R&D investments. Observability makes it possible to contract on R&D and solve free-riding problem as e¤ectively as the establishing of RJV.

In this study we focus rather on ex ante cooperation which is not limited to RJVs. The …rms just agree in advance to share R&D results but not R&D costs. Following Katsoulacost and Ulp (1998) the intensity of cooperation is assumed to be endogenous. In most studies the intensity of cooperation is taken as given.

Whether the independent …rms can …nally agree on anything depends on the nature of their observations. If only real R&D results, but not real R&D e¤orts, can be observed veri…ably there arise moral hazard and a free-rider problem. Then …rms can contract on sharing R&D results but not on R&D e¤orts (real investments) themselves.

This study focuses explicitly on the available information structure. In the basic model the …rms cannot observe the real R&D of their partner, whereas we abstract from asymmetric information concerning …rms' abilities, discussed by Gandal and Scotchmer (1994).

In almost all studies which concern R&D the …rms are assumed to be risk-neutral. But we consider a model in which the …rms are risk averters. The implications of this study are founded strongly on the assumed risk-averseness of the …rms. We think that in real life the …rms are rather risk-averters more often than risk-neutral. This is also indicatied by the quite common tendency of the …rms to diversify a product portfolio and to locate production in di¤erent countries in order to lessen the risks associated with the functioning of the labour market and the development of labour costs.

In the model considered, …rms contract at the …rst stage on the intensity of cooperation and at the second stage on the research e¤ort. A …rm's utility is assumed to be separable in R&D e¤orts and investments so that there arise no advantages, owing to complementary actions, that could motivate the cooperation of independent …rms. Neither does there exist any kind of duplication that creates an opportunity for costs savings through coordination.

It turns out that, in the absence of monitoring, the …rms choose either high e¤ort and low intensity of cooperation or, alternatively, low e¤ort and maximal intensity of cooperation.

When …rms are risk averse they can, ceteris paribus, increase their utility through cooperation, which diversi…es their R&D project portfolio. On the other hand, because the partners' R&D e¤ort is unobservable, the …rms which maximize their pro…ts by equating marginal bene…ts and costs of R&D take into account only the results of their own R&D which results in moral hazard and low level of R&D. Maximal bene…t from a …rm's own R&D is obtained during isolation. If a …rm is risk averse, there arises a trade-o¤ between increasing the utility by diversifying the portfolio of R&D projects through cooperation and maximizing the results from a …rm's own R&D through isolation. If there are no complementarities in R&D research or in the product market, the latter motive easily dominates.

We enlarge the model to also cover those cases in which a …rm can monitor a partner's real R&D e¤ort through a signal. In the model considered an e¤ort can be either high or low. The signal tells more or less accurately about the nature of real e¤ort. If the signal is low, a …rm can ensure that the partner's e¤ort has been low. Monitoring gives an opportunity to add to a contract a paragraph according to which the sharing contract can be cancelled, if a signal is low. It can be shown that monitoring, before becoming perfect, weakens moral hazard to an extent that risk averse and independent …rms choose high e¤ort and maximal intensity of cooperation even if they were indi¤erent between high e¤ort and low e¤ort during isolation. The risk-neutral …rms would then choose low e¤ort, given the intensity of cooperation is above zero. Besides, their attitude toward cooperation would be indeterminate.

In the basic model considered, each …rm has an independent research plan which is aimed at a discovery which is located in another area than a partner's innovation. In cooperation the utilization of these independent innovations does not lead to duplication of R&D and, on the other hand, cooperation reduces risk through diversi…cation in an e¢cient way. We also consider a case which is more frequently discussed in the literature (see e.g. Stenbacka and Tombak, 1998). In this case …rms' discoveries aim at an innovation in the same area. A …rm's e¤ort is a perfect substitute of its partner's e¤ort when both have success in their discoveries. In this case the tendency towards diversi…cation still motivates cooperation. But the duplication which occurs when both …rms are successful, tightens those conditions under which intensive cooperation is chosen.

In the simpli…ed model of this study conduct in the product market is not modelled separately. It is, however, implicitly assumed that competition in the product market increases with the intensity of cooperation. I assume that the sum of the pro…ts of the two …rms considered does not change when the intensity of cooperation increases. This situation can arise, if the …rms are engaged in Cournot competition during cooperation, and if they have monopoly in isolation. It is still posible that a part of those pro…ts which are created by an innovation spills to other …rms even if there is no contracted cooperation.

We also discuss a case in which the …rms di¤er from each other in their capability to utilize R&D results. When asymmetry in this sense increases, the conditions under which …rms cooperate tighten.

The case in which potential cooperators are located in complementary industries is also discussed. For example, e.g. Katsoulacost and Ulp (1998) and many others have noticed that the incentives to cooperate con…rm remarkably, if the …rms are located in the complementary industries. In the model considered this result also holds good.

The e¤ect of public subsidies is also analysed. Society's welfare is no doubt highest when a firm's effort is high and when they cooperate. This situation implies competition in the product market that benefits consumers, and higher R&D investments, which narrows the gap between public and private incentives to invest in R&D. At best, these subsidies can improve social welfare and raise efforts without weakening the motives to cooperate. If public subsidy is efficient it should be based on monitored R&D efforts. Alternatively, a subsidy can be based on observed success.

Lately, Horvath (1999) has discussed the fact that debt-ridden firms who cannot contract on sharing of information could be inclined to disclose some information voluntarily. This effect is based on the fact that the firms in debt are interested only in an upper section of their profit distribution, which may make a firm's marginal benefits from R&D respond positively to other firms' R&D. As a result of larger leverage the firms would share some R&D knowledge. If this is true, public aid in the form of loans can promote information-sharing through a leverage effect.

2 Basic model-symmetric firms

We consider a two firm-model in which the firms may share information originating in individual R&D projects. The firms decide about the amount of real R&D investments, called efforts, which affects the success of the project. The firms also agree on the intensity of co-operation. A decision on co-operation is by nature a strategic decision and this decision is made at the first stage of the game. An effort decision is made on the second stage. The firms considered are referred to by subscript A and B. Let v denote the intensity of co-operation. Then v is continuous and $v \in [0;1]$. Gross-benefits from firm A's own innovation are normalized to be one. Firm B's gross benefits are also of size one. Let α_A denote that part of the shared profits from A's innovation which is captured by firm A. Respectively, γ_A denotes that part of the shared profits from B's innovation which is captured by firm A. It is still possible that under isolation, due to involuntary spillovers, part δ_A^B of gross profits leaks to firm B. Then δ_B^A denotes that part of B's profits which involuntarily leaks to firm A. Using these definitions, firm A benefits from its own innovation by amount $(1-v)(1-\delta_A^B)$ and from B's innovation by the amount $(1-v)\delta_B^A + v\gamma_A$. Let p_A denote the probability that A's project is succesful and, respectively, p_B the probability for the succes in B's project.

A's utility is then

$$U_A = p_A U((1-v)(1-\delta_A^B) + \alpha_A v) + p_B U((1-v)\delta_B^A + v\gamma_A) - e_A.$$

The above $(1-v)$ describes that part of a firm's own efforts which are not shared with a partner. If firms do not cooperate, $v = 0$ and

$$U_A = p_A U(1-\delta_A^B) + p_B U(\delta_B^A) - e_A.$$

On the other hand, during fully intensive cooperation $v = 1$, and

$$U_A = p_A U(\alpha_A) + p_B U(\gamma_A) - e_A.$$

From all viewpoints, involuntary leakages δ_A^B and δ_B^A are very small so that $1-\delta_A^B$ is, in any case, much larger than α_A, and γ_A respectively much larger than δ_B^A. This lets us simplify the model by assuming that $\delta_A^B = 0$ and $\delta_B^A = 0$ without any loss of generality. It must be noticed that it is still possible that firm A's and B's R&D results are imperfectly approbriable in the sense that part of it leaks to the rest of the industry. This spillover must not be taken explicitly into account, because cooperation between firms A and B only is considered.

It is supposed that if the firms are competitors, then

$$\begin{aligned} \alpha_A + \gamma_B &= 1 \\ \alpha_B + \gamma_A &= 1. \end{aligned} \qquad (1)$$

This assumption is a simplification as well. It implies that sharing R&D knowledge which, in the product market, increases competition does not change total profits accrued from innovation. This is possible when a firm obtains monopoly profits while being alone, and, respectively, duopoly profits ala Cournot competition during cooperation. Total profits remain constant, especially if there are decreasing returns, or if, despite the similarity of innovation, firm A's final product differs a little from firm B's final product.

We assume that $\alpha_A \geq \gamma_A$; which says that each firm is more capable of utilizing its own R&D results than R&D produced by another firm. If these firms are equally efficient in absorbing shared information, then $\alpha_A = \alpha_B$ and $\gamma_A = \gamma_B$. But if firm A is more efficient, then $\alpha_A > \alpha_B$ and $\gamma_A > \gamma_B$. If the firms do not compete with each other it is possible that $\alpha_A + \gamma_B > 1$ and $\alpha_B + \gamma_A > 1$. It is possible, for example, that firm B is firm A's client and that they stay at the different levels of the vertically integrated production chain. Then the information utilized by A does not, necessarily, hurt firm B.

For simplicity is assumed that an effort is a dichotomous variable. Firm A is not able to observe or control firm B's effort, and vice versa. This yields a moral hazard problem. High effort is denoted by e^H and low effort by $e^L (< e^H)$. The monetary cost of effort is directly related to the effort levels. In the considered setting, effort only affects the probability of success, not the amount of gross benefits. If firm A's efforts are high, the probability of success is p_A^H. This probability exceeds p_A^L, which denotes the probability of success when A's effort is low. It is assumed that failure gives zero gross benefits. In the basic model, considered in this section, the firms A and B are similar in the sense that $p_B^H = p_A^H$, $\alpha_A = \alpha_B$ and $\gamma_A = \gamma_B$.The firm's utility function U is assumed to be strictly concave and U' strictly convex. Given these definitions A's utility is

$$U_A^H = p_A^H U(1 - v + \alpha_A v) + p_B U(v\gamma_A) - e_A^H \tag{2}$$

when A exerts high effort. In the case in which firm A's effort is low its utility is respectively

$$U_A^L = p_A^L U(1 - v + \alpha_A v) + p_B U(v\gamma_A) - e_A^L. \tag{3}$$

From (2) and (3) it is seen that the utility function is separable in success probabilities and does not depend on a partner's effort costs. Thus, research efforts do not complement each other and there is no duplication in research activity which could give reasons for cooperation.

Let $U_i(e_i^H, e_j^H)$ describe firm i's utility when both firms exert high effort. For (e_i^H, e_j^H) to be a Nash equilibrium in terms of chosen effort it is required that $U_i(e_i^H, e_j^H) > U_i(e_i^L, e_j^H), i = A, B$. The respective Nash condition for (e_i^L, e_j^L) is $U_i(e_i^L, e_j^L) > U_i(e_i^H, e_j^L), i = A, B$. We assume that $e_A^H = e_B^H$ and $e_A^L = e_B^L$ and use notation e^H for high effort and e^L for low effort. From equations (2) and it (3) follows that there exists an equilibrium for high efforts, if $U_A^H > U_A^L$. This requires that

$$(p_A^H - p_A^L)U(1 - v + \alpha_A v) - (e_A^H - e_A^L) > 0. \tag{4}$$

Because of symmetry similar conditions, however, concern firm B. If condition (4) is valid (e_A^H, e_B^H) is a Nash equilibrium for firm A. If, however, the left-hand side of (4) were negative, (e_A^L, e_B^L) would be a Nash-equilibrium in the considered setting.

Notice that condition (4) does not depend on B^{0}s conduct. In fact, the negative sign of the left hand side of (4) holds when it does not pay for A to deviate from low e¤ort equilibrium.

Proposition 1 When cooperation becomes more intense, the incentives to set high e¤ort weaken.

Proof. $®_A < 1$, wherefore in (4) $(1 ¡ v)z_A + ®_A v z_A$ decreases in v; which proves the proposition. ■

When …rm A does not co-operate $v = 0$, and condition (4) can be written in the form

$$(p_A^H ¡ p_A^L)U(1) ¡ (e_A^H ¡ e_A^L) > 0: \quad (5)$$

Because the left-hand side of (4) decreases in v, it is clear that the motive to exert e¤ort weakens when the intensity of co-operation increases. If …rm A were indi¤erent or almost indi¤erent between e_A^H and e_A^L in isolation, …rm A would select low e¤ort in any kind of co-operation with $v > 0$:

Corollary 1 If a …rm in isolation is indi¤erent between low and high e¤ort, it always sets low e¤ort when there is any kind of cooperation.

Proof. When (5) is binding condition (4) transforms into

$$(p_A^H ¡ p_A^L)U(1 ¡ v + ®_A v) > (p_A^H ¡ p_A^L)U(1);$$

which is invalid because $1 ¡ v + ®_A v < 1$ when $v > 0$. ■

This result shows that the moral hazard e¤ect is dominant. The opportunity to diversify the research project portfolio and decrease risk in this way is still too weak.

If $(p_A^H ¡ p_A^L)U(1)$ is, however, much above $e_A^H ¡ e_A^L$, it is possible that there exists such a cut-o¤ value for v, denoted by v^c, that is located in the range $(0; 1)$ and speci…es the level at which the agent is indi¤erent between being e¢cient and ine¢cient. If $v < v^c$, the …rm exerts high e¤ort. If, on the other hand, $v < v^c$, …rms set low e¤ort. A cut-o¤ value v^c is determined by the equation

$$(p_i^H ¡ p_i^L)U(1 ¡ v + ®_i v) ¡ (e_i^H ¡ e_i^L) = 0 \quad (6)$$

for $i = A; B$. We …rst consider an equilibrium at which …rms A and B are identical competitors. Then also $p_A^H = p_B^H$ and $z_A = z_B$:

If $v^c \geq 1$, both firms always select low effort. Under symmetry optimal behaviour is determined from

$$\frac{\partial U_A^L}{\partial v} = p_A^L(1 - \alpha_A)[-U'(1 - v + \alpha_A v) + U'(v\gamma_A)]. \qquad (7)$$

Due to U's concavity and the fact that in (7) $1 - v + \alpha_A v > v\gamma_A$, expression (7) is positive. This means that the firms set $v = 1$ when effort is low. The intensity of cooperation is then the highest possible.

Let us then consider the cases where $0 < v^c < 1$. Because a partner's choice has no effect on the firm's own choice and because of symmetry, only one of two Nash conditions can be valid. Firm A's optimization problem is to find out

$$\max_v U_A^H \equiv \bar{U}_A^H \text{ when } v < v^c$$

$$\max_v U_A^L \equiv \bar{U}_A^L \text{ when } v > v^c.$$

Finally firm A chooses $\max(\bar{U}_A^H, \bar{U}_A^L)$. The choice at this stage also determines the chosen the intensity of co-operation. Because of symmetry, firm B's choices are similar to firm A's choices. This is also noticed by firm A.

Suppose that $0 < v^c < 1$. When v is on the range $(v^c, 1)$ the firm maximizes U_A^L with respect to v, which gives $v = 1$.

When $0 < v < v^c$ both firms exert high effort and the agent maximizes U_A^H with respect to v on the range. The following is obtained

$$\frac{\partial U_A^H}{\partial v} = -p_A^H(1 - \alpha_A)U'(1 - v + \alpha_A v) + p_B^H\gamma_A U'(v\gamma_A). \qquad (8)$$

Due to symmetry and the fact that $1 - \alpha_A = \gamma_A$, $\frac{\partial U_A^H}{\partial v}$ above is positive if $U'(1 - v + \alpha_A v) < U'(v\gamma_A)$. Because U is strictly concave and assumptions $\gamma_A + \alpha_A = 1$ and $\gamma_A \leq \alpha_A$ imply that $\gamma_A < \frac{1}{2}$, this requirement is met. Thus $\frac{\partial U_A^H}{\partial v} > 0$ in (8). In other words, intensity v is set as high as possible which is v^c.

Proposition 2 *The higher the cut-off value v^c is, the more likely it is that high effort is chosen.*

Proof. Firm A now knows that insofar as $0 \leq v < v^c$, firm B also chooses high effort. The highest possible v which still guarantees high effort is arbitrarily close to v^c. Therefore, $\bar{U}_A^H$ has, in the case considered, the expression

$$\bar{U}_A^H = p_A^H U(1 - v^c + \alpha_A v^c) + p_B^H U(v^c\gamma_A) - e_A^H.$$

When $v^c < v \le 1$, however, low effort is chosen. In this case firms will also make cooperation very intensive and set $v = 1$: If $v = 1$, firm A knows that firm B will set $e_B = e_B^L$. Thus the following is obtained for $\tilde{U}_A^L$

$$\tilde{U}_A^L = p_A^L U(\alpha_A) + p_B^L U(\gamma_A) - e_A^L.$$

The firms choose low effort and $v = 1$, if $\tilde{U}_A^L$ above exceeds $\tilde{U}_A^H$. Using the fact that

$$(p_A^H - p_A^L)[U(1 - v^c + \alpha_A v^c)] - (e^H - e^L) = 0;$$

the following is obtained for inequality $\tilde{U}_A^H > \tilde{U}_A^L$:

$$p_A^L U(1 - v^c + \alpha_A v^c) + p_B^H U(v^c \gamma_A) - p_A^L U(\alpha_A) - p_B^L U(\gamma_A) > 0. \qquad (9)$$

Taking into account that $p_A^L = p_B^L$ and $p_A^H = p_B^H$, the left-hand side of (9) is negative when $v^c = 0$ and positive when $v^c = 1$. Besides, the left-hand side of (9) increases in v^c. This shows that when the cut-off point v^c is near 1, the intensity of cooperation is almost v^c and effort is set at a high level, whereas when the cut-off point v^c is remarkably lower than 1; firms decide to co-operate very intensively so that $v = 1$. This, however, exacerbates the free-rider problem and leads to low efforts. ■

As a conclusion to this section one can state that at the second stage, when an effort decision is made, the moral hazard (or free-rider) problem creates pressure towards low effort. The decision at the first stage, which concerns the intensity of co-operation, is strategic and takes into account the first stage decision.

Being a risk averter a firm faces a trade-off between higher incentives to exert effort and diversification of its R&D asset portfolio. More intense co-operation promotes diversification at the expense of efforts. These motives appear when the optimization problem is broken down into two stages. At the first stage, when the intensity of cooperation is decided, given the efforts (see conditions (8) and (7)), a risk averse firm will intensify cooperation without limit. If the utility function U is linear which, means that firms are risk-neutral, there arises no tendency at the first stage to intensify cooperation. In fact, risk-neutral firms were indifferent about the value of v in their first stage decisions.

Because a risk-neutral firm is not interested in diversification, the final equilibrium is also quite different from the case in which firms are risk averters. This is seen by assuming that U is linear in inequality (9). Condition

(9) then transforms into the form

$$p_A^L(1 - v^c + \alpha_A v^c) + p_B^H v^c \gamma_A - p_A^L \alpha_A - p_B^L \gamma_A > 0.$$

Taking into account that $\gamma_A = 1 - \alpha_A$, the above inequality reduces to

$$(p_A^H - p_A^L) v^c \gamma_A > 0,$$

which is always true. This means that when firms are risk-neutral, they prefer always a combination of high effort and low intensity of cooperation to a combination of low effort and high intensity of cooperation. Furthermore, when risk-neutral firms decide to restrict the intensity of cooperation to value lower than v^c they are indifferent between various values for v in the range $[0, v^c)$.

3 Contracting on efforts in symmetry

We suppose in this section that the firms can observe signals which denote more or less credibly the type of effort chosen. These signals are denoted by $s_i, i = A, B$. When firm A observes that $s_B = s_B^H$, the probability that B actually exerts high effort denoted by $p(e_B^H/s_B^H)$ is q. Then $p(e_B^L/s_B^H) = 1 - q$. Because the signal s_B^H is informative, $q > \frac{1}{2}$. If A observes s_B^L, A has got verifiable evidence that $e_B = e_B^L$. Thus $p(e_B^L/s_B^L) = 1$ and $p(e_B^H/s_B^L) = 0$.

It is also assumed that if A exerts high effort, it can ensure that the signal is s_A^H. In other words, $p(s_A^H/e_A^H) = 1$, from which it follows that $p(s_A^L/e_A^H) = 0$. If firm A sets e_A^L, the signal observed by B can, however, be either s_A^L or s_A^H. It is assumed that $p(s_A^L/e_A^L) = k$ and that $k > \frac{1}{2}$. Then $p(s_A^H/e_A^L) = 1 - k$. It is evident that set s_A^H is larger than set e_A^L, wherefore $1 - k > 1 - q$ (and $k < q$), but this property is unimportant as far as it concerns the implications of the model.

Signal comes after efforts. Firms are assumed to be able to use signals in revising the contract concerning R&D co-operation. The time structure in the considered setting is the following:

1) Firms contract on the intensity of co-operation. 2) Firms set effort levels. 3) Firms observe signals concerning effort levels. 4) If signal s_i^L is observed firm j $(\neq i)$ has sufficient evidence to cancel co-operation, which

results in $v = 0$. 5) The outcome of R&D projects is materialized as either success or failure.

We also assume that signal s_B^L is valuable for firm A when firm A has set high effort, and vice versa. This means that if A has observed s_B^L it pays for A to cancel the contract concerning cooperation, by which v becomes zero. This requires that

$$p_A^H U(1) > p_A^H U(1 - v + \alpha_A v) + p_B^L U(v\gamma_A); \tag{10}$$

when $v > 0$.

In the case considered efforts are set first. After that, signals are observed. So, when a firm exerts effort it just believes that its partner's effort is either high or low. If a firm finds that the state at which both set high effort is an equilibrium and if this equilibrium dominates the state at which both firms set low effort, high effort strategy is chosen. It should be noticed that the possibility to observe signals brings about a disadvantage for a firm who deviates from high effort equilibrium.

Suppose firm A believes that firm B exerts high effort. When A sets $e_A = e_A^H$ its utility is given in equation (2), whereas, if A sets $e_A = e_A^L$, firm B observes s_A^L with probability k, and cancels the contract concerning cooperation. In that case A's utility is

$$\begin{aligned} U_A^L &= (1 - k)p_A^L U(1 - v + \alpha_A v) + kp_A^L U(1) \\ &\quad +(1 - k)p_B^H U(v\gamma_A) - e_A^L. \end{aligned} \tag{11}$$

Firm A does not deviate from high effort equilibrium, if U_A^H from (2) is larger than U_A^L in (11). That says

$$\begin{aligned} &[p_A^H - (1 - k)p_A^L]U(1 - v + \alpha_A v) + kp_B^H U(v\gamma_A) - kp_A^L U(1) \\ > \; & e_A^H - e_A^L \end{aligned} \tag{12}$$

Proposition 3 Suppose that a firm in isolation is indifferent between high and low effort. If monitoring is efficient enough, it is then possible that high effort equilibrium exists although firms cooperate.

Proof. If (5) is binding then (12) is valid, if

$$\begin{aligned} &p^H[U(1 - v + \alpha_A v) + kU(v\gamma_A) - U(1)] \\ &+(1 - k)p^L[U(1) - U(1 - v + \alpha_A v) \\ > \; & 0. \end{aligned} \tag{13}$$

The above notation $p^H \equiv p_A^H = p_B^H$ and $p^L \equiv p_A^L = p_B^L$ is used. Due to the strict concavity of U, the first term in (13) is positive, if k is close enough to one and $v > 0$. The second term is positive in any case. The left hand side of (13) increases in k. When $k = 0$, the left-hand side is negative and when $k = 1$, the left-hand side is positive. From this it follows that there must be a cut-off value k^c for k which makes (13) binding. If $k > k^c$, monitoring guarantees that high effort equilibrium exists . ■

When (5) is binding, v^c is zero for a risk-neutral agent. This explains why the left hand side of (13) is negative when $k < 1$ and zero when $k = 1$ and $v > 0$. The risk-neutral agent would then exert low effort if $v > 0$. This shows that monitoring combined with risk aversion strengthens the incentives to cooperate.

High effort equilibrium should be compared with low effort equilibrium. It can be shown that when firm A exerts low effort it does not pay for it to cancel cooperation, if it observes s_B^L. Under symmetry this implies that in low effort equilibrium a contract is not cancelled, even if a low signal is observed. The accuracy of monitoring has no effect on the conditions which determine the existence of low effort equilibrium. In the setting considered, the existence of low effort equilibrium thus requires that

$$(p_A^H - p_A^L)U(1 - v + \alpha_A v) - (e_A^H - e_A^L) < 0. \tag{14}$$

If (14) is valid, deviation from the low effort state is not profitable, if the partner has also set low effort. In fact, condition (14) is the negation of condition (4). So the validity of (14) implies that high effort equilibrium does not exist in the absence of monitoring. Condition (14) can, however, be valid simultaneously with conditions (5) and (13).

Corollary 2 If condition (12) is in force, with any positive v, then high effort equilibrium dominates low effort equilibrium (if it exists)

Proof. In order to derive $\tilde{U}_A^H$,

$$U_A^H = p_A^H U(1 - v + \alpha_A v) + p_B^H U(v\gamma_A) - e_A^H$$

is maximized with respect to v. This yields $v = 1$. So, $\tilde{U}_A^H$ has the expression

$$\tilde{U}_A^H = p_A^H U(\alpha_A) + p_B^H U(\gamma_A) - e_A^H. \tag{15}$$

Would firms, however, choose low effort, which is also an equilibrium insofar as condition (14) is in force. Suppose that (e_A^L, e_B^L) is an equilibrium as well. In this equilibrium firms also cooperate with maximal intensity, that is $v = 1$. A's utility in this low effort equilibrium is

$$\bar{U}_A^L = p_A^L U(\alpha_A) + p_B^L U(\gamma_A) - e_A^L.$$

Taking into account that $p_A^H = p_B^H$ and $p_A^L = p_B^L$, an inequality $\bar{U}_A^H > \bar{U}_A^L$ reduces into the form

$$(p_A^H - p_A^L)[U(\alpha_A) + U(\gamma_A)] - (e_A^H - e_A^L) > 0.$$

But the above $U(\alpha_A) + U(\gamma_A) > U(1)$, because U is strictly concave and $\alpha_A = 1 - \gamma_A$. This, together with the assumed validity of condition (5), ensures that the above inequality is in force. ■

This proves that portfolio diversification can play a major role in R&D cooperation.

It must be noticed that with perfect monitoring $k = 1$. Then there exists high effort equilibrium with $v = 1$ and firms prefer high effort equilibrium to low effort equilibrium. This case corresponds to a situation, discussed among others by Kamien et al. (1992), where the firms also decide to share investments. To be able to contract on R&D investments (efforts) they must be observed verifiably by both parties. High intensity of cooperation combined with high efforts is not a new result. From various approaches many authors, Reinganum (1981), Motta (1992) and Vonotars (1994) have come to the conclusion that cooperative investments are stimulated by larger spillovers. The strengthening of "spillovers" is equivalent to the intensifying of cooperation in our model. It must, however, be stressed that in our model this effect arises exclusively due to the risk aversion of the firms.

Signals and efforts are simultaneous We next consider the time structure in which a firm observes the signal of its partner's effort at the same time as it sets its own effort. High effort always leads to signal s_i^H, which does not, however, tell that $e_i = e_i^H$ with certainty. The behaviour considered now is qualitatively different from the behaviour discussed in the previous section. Now the reactions through efforts are based on real observations. In previous sections they were based rather on beliefs concerning the partner's behaviour.

Let us consider the conditions under which (e_A^H, e_B^H) is a Nash equilibrium under quick monitoring. Suppose firm B has set $e_B = e_B^H$. Then firm A observes s_B^H. When A sets $e_A = e_A^H$ its utility is

$$U_A^H = p_A^H U(1 - v + \alpha_A v) + (qp_B^H + (1 - q)p_B^L)U(v\gamma_A) - e_A^H. \quad (16)$$

In (16) the signal s_B^H does not give 100 percent evidence that $e_B = e_B^H$. With probability $(1 - q)$ B's effort is low, whereas, if $e_A = e_A^L$ and $s_B = s_B^H$, the following is obtained

$$\begin{aligned} U_A^L &= (1 - k)p_A^L U(1 - v + \alpha_A v) + kp_A^L U(1) \\ &\quad + (1 - k)(qp_B^H + (1 - q)p_B^L)U(v^c\gamma_A) - e_A^L. \end{aligned} \quad (17)$$

In (17) the probability that firm B cancels the contract because of A's low effort is k. If the contract is denounced, firm A gets no benefit from B's R&D. It should also be noticed that when A exerts high effort, B cannot get a low signal (s_A^L) and a reason to give notice to quit.

If U_A^H in (16) is larger than U_A^L in (17) it is not worth deviating from the high effort strategy given v. The condition for $U_A^H > U_A^L$ in the case considered is

$$\begin{aligned} &(p_A^H - p_A^L)U(1 - v + \alpha_A v) + kp_A^L U(1 - v + \alpha_A v) \\ &- kp_A^L U(1) + k(qp_B^H + (1 - q)p_B^L)U(v^c\gamma_A) \\ > \;& e_A^H - e_A^L. \end{aligned} \quad (18)$$

Comparing condition (18) with condition (12) shows that simultaneous and incomplete monitoring can, in fact, weaken those conditions under which high effort equilibrium is chosen. If in (18) monitoring is accurate so that kq is close enough to one, all the implications of the previous section which concerned behaviour during monitoring hold. So, also during coincidence of effort setting and its observation, risk aversion promotes cooperation. This conclusion is reinforced by the following proposition.

Proposition 4 Suppose that a firm chooses high effort in isolation so that (5) is valid. Then the firms in cooperation choose high effort at least, if

$$U(1 - v + \alpha_i v) + kqU(v\gamma_i) - U(1) \geq 0. \quad (19)$$

Proof. The left-hand side of (18) can be written in the form $(p_A^H - p_A^L)U(1) + B$, where

$$\begin{aligned} B = \;& p_A^H[-U(1) + U(1 - v + \alpha_A v) + kqU(v\gamma_A)] \\ & + p_A^L[U(1) - U(1 - v + \alpha_A v) + kU(1 - v + \alpha_A v) \\ & - kU(1) + k(1 - q)U(v\gamma_A)]. \end{aligned}$$

Above, strict concavity of U yields $kU(1 - v + \alpha_A v) - kU(1) + k(1 - q)U(v\gamma_A) > kqU(v\gamma_A)$ in symmetry. This guarantees that $B > 0$ from which it follows that

$$(p_A^H - p_A^L)U(1) + B > (p_A^H - p_A^L)U(1).$$

■.

Proposition (4) shows that in the trade-off between free rider extrenality which tends to lower effort, and the diversification motive which tends to enforce effort incentives, the latter motive becomes dominant when a firm tightens control over a partner's efforts.

3.1 Asymmetric firms

Asymmetry in absorptive capacity Asymmetry can exist in several ways. Firstly, another firm can be more effective than its partner in exploiting R&D produced by itself or by a partner. If firm A is more effective then $\alpha_A > \alpha_B$ and $\gamma_A > \gamma_B$ under restrictions $\alpha_A + \gamma_B = 1$ and $\alpha_B + \gamma_A = 1$. In this case it is possible that firm A can exploit firm B′s R&D results even more effectively than firm B itself. This says that $\alpha_A > \gamma_B$, although $\alpha_A > \gamma_A$ and $\alpha_B > \gamma_B$.

Secondly, the efficiency differences can refer to the ability to produce innovations. If firm A is more efficient than firm B in this respect, $p_A^H > p_B^H$ which implies that $p_B^L > p_A^L$.

Let us first consider a case in which $\alpha_A > \alpha_B$ and $\gamma_A > \gamma_B$. Still, $\alpha_A + \gamma_B = 1$ and $\alpha_B + \gamma_A = 1$, $\alpha_A > \gamma_A$ and $\alpha_B > \gamma_B$. It is assumed that $\gamma_A + \gamma_B = C$ when C is constant.

Because $\alpha_A > \alpha_B$ and $\gamma_A > \gamma_B$, it follows from equation (5) that $v_A^c > v_B^c$ when v_i^c denotes firm i′s $(i = A; B)$ cut-off value.

If $0 < v < v_B^c$, $e_A = e_A^H$ and $e_B = e_B^H$. If $v_B^c < v < v_A^c$, $e_A = e_A^H$ and $e_B = e_B^L$ and finally, if $v_A^c < v < 1$, $e_A = e_A^L$ and $e_B = e_B^L$.

By the definition of v_B^c, when setting high effort firm B always prefers v_B^c to v_A^c. If the intensity of co-operation becomes larger than v_B^c firm B starts to set low effort and then it prefers maximal intensity, as firm A also does. In the setting considered v_A^c is not an equilibrium level for v.

There seem to be two alternatives for firms A and B: Either $v = v_B^c$, which defines an equilibrium $(e_A^H; e_B^H)$. The other alternative is $v = 1$, which defines low effort equilibrium $(e_A^L; e_B^L)$. Let us consider how these equilibria react when α_A and γ_A increase at the expense of parameters α_B and γ_B.

When $v = v_B^c$, it obtained for U_A and U_B

$$U_A^H = p_A^H U(1 - v_B^c + \alpha_A v_B^c) + p_B^H U(v_B^c \gamma_A) - e_A^H.$$

$$U_B^H = p_B^H U(1 - v_B^c + \alpha_B v_B^c) + p_A^H U(v_B^c \gamma_B) - e_B^H.$$

Taking into account that $\gamma_B = C - \gamma_A$, $\alpha_B = 1 - \gamma_A$ and $\alpha_A = 1 - C + \gamma_A$, the equations above can also be written as

$$U_A^H = p_A^H U(1 - v_B^c C + v_B^c \gamma_A) + p_B^H U(v_B^c \gamma_A) - e_A^H. \quad (20)$$

and

$$U_B^H = p_B^H U(1 - v_B^c \gamma_A) + p_A^H U(v_B^c (C - \gamma_A)) - e_B^H. \quad (21)$$

Respectively, when $v = 1$, the following is obtained:

$$U_A^L = p_A^L U(1 - C + \gamma_A) + p_B^L U(\gamma_A) - e_A^L \quad (22)$$

and

$$U_B^L = p_B^L U(1 - \gamma_A) + p_A^L U(C - \gamma_A) - e_B^L. \quad (23)$$

From (6) we obtain the equation

$$(p_B^H - p_B^L) U(1 - v_B^c \gamma_A) - (e_B^H - e_B^L) = 0,$$

which defines v_B^c as a function of γ_A. Then $\frac{\partial v_B^c}{\partial \gamma_A} = -\frac{v_B^c}{\gamma_A}$. Using this result it is possible to examine how the left-hand side of equations (20) - (23) change when γ_A increases and with it α_A also at the expense of γ_B and α_B.

Differentiating equations (20) - (23) with respect to γ_A yields

$$\frac{\partial U_A^H}{\partial \gamma_A} = p_A^H U'(1 - v_B^c \gamma_B) \frac{\gamma_A + \gamma_B}{\gamma_A} v_B^c > 0.$$

$$\frac{\partial U_B^H}{\partial \gamma_A} = -p_A^H U'(v_B^c \gamma_B) \frac{\gamma_A + \gamma_B}{\gamma_A} v_B^c < 0.$$

$$\frac{\partial U_A^L}{\partial \gamma_A} = p_A^L U'(1 - \gamma_B) + p_B^L U'(\gamma_A) > 0$$

$$\frac{\partial U_B^L}{\partial \gamma_A} = -p_B^L U'(1 - \gamma_A) - p_A^L U'(\gamma_B) < 0.$$

The results above show that the increase of γ_A which is connected with an increase in α_A and decrease in α^B and γ_B improves firm A's situation but deteriorates firm B's situation. In high effort equilibrium the increase in γ_A has a direct and also an indirect effect through a decrease in v_B^c. The direct effect, however, dominates, which explains why firm A's utility increases and firm B's utility decreases. In low effort equilibrium, v is fixed to be one, wherefore there is only a direct effect from γ_A to utilities U_A^L and U_B^L.

It is thus clearly in the firm's interests to find partners which are relatively inefficient in utilizing information that has arisen in R&D projects. But other firms will not cooperate with firms which are more efficient in this respect. It is evident that in the market it is easiest for similar firms rather than for dissimilar firms to conclude an agreement concerning cooperation. On the whole, one would expect that the average type of firms find partners more easily than exceptionally efficient or inefficient firms.

Firms could also trade on dissimilarity. But this requires a more exact contract. It would no longer be sufficient to decide only about the intensity of cooperation. The relative differences in absortive capacity should also be specified. Naturally, transaction costs related to contract would rise. The required complexity of the contract would also prevent cooperation between dissimilar partners.

Let us finally consider the case in which an efficient firm, however, cooperates with an inefficient firm. Taking into account the assumed restrictions concerning model parameters, the condition which says when firm A prefers high effort and low intensity ($v = v_B^c$) compared with low effort and high intensity of co-operation is

$$\begin{aligned} & p_A^H U(1 - v_B^c C + v_B^c \gamma_A) + p_B^H U(v_B^c \gamma_A) \\ & - p_A^L U(1 - C + \gamma_A) - p_B^L U(\gamma_A) - (e_A^H - e_A^L) \\ > \; & 0. \end{aligned} \tag{24}$$

For firm B the respective condition is of the form

$$\begin{aligned} & p_B^H U(1 - v_B^c \gamma_A) + p_A^H U(v_B^c C - v_B^c \gamma_A) \\ & - p_B^L U(1 - \gamma_A) - p_A^L U(C - \gamma_A) - (e_B^H - e_B^L) \\ > \; & 0. \end{aligned} \tag{25}$$

Let $LH1$ denote the left-hand side of (24) and $LH2$ the left-hand side of (25). Then

$$\frac{\partial LH1}{\partial \gamma_A} = p_A^H U'(z_A(1 - v_B^c \gamma_B)) \frac{\gamma_A + \gamma_B}{\gamma_A} v_B^c z_A$$

$$-p_A^L U'(\alpha_A z_A) - p_B^L U'(\gamma_A z_B).$$

When asymmetry becomes deep so that v_B^c is very small, the partial derivative $\frac{\partial LH1}{\partial \gamma_A}$ easily becomes negative. This shows that an increase in α_A and γ_A make low level of effort and very intensive co-operation more tempting for firm A. From equation (25) it is obtained

$$\begin{aligned}\frac{\partial LH2}{\partial \gamma_A} &= p_A^H U'(v_B^c \gamma_B))\frac{\gamma_A + \gamma_B}{\gamma_A} v_B^c \\ &\quad + p_B^L U'(\alpha_B) + p_A^L U'(\gamma_B).\end{aligned}$$

Above the sign of $\frac{\partial LH2}{\partial \gamma_A}$ is ambiguous even when v_B^c is very small. When $U(x)$ is, for example, of the form $-e^{-x}$ $\frac{\partial LH2}{\partial \gamma_A}$ is easily positive when v_B^c is small. If $LH2$ is positive firm B prefers very high efforts combined with low level co-operation.

Asymmetry in ability to succeed in R&D projects Assume that firm A is more successful in R&D activity than firm B. Then $p_A^H > p_B^H$ and $p_A^L > p_B^L$. We assume for simplicity that $p_A^H - p_A^L = p_B^H - p_B^L$. In the situation considered the intensity of co-operation in high effort equilibrium is the same as in the symmetric case. But firm B benefits from its more effective partner, whereas firm A loses, owing to firm B's inefficiency. Again, one would imagine that, in the market of many firms, it is easier for similar firms to contract with each other than for dissimilar firms.

4 Vertically integrated firm structure

So far we have considered competing firms only. Then it is reasonable to assume that $\alpha_A + \gamma_B = 1$. Suppose firm A is either firm B's client or deliverer. Firms A and B do not compete with each other. But locating in complementary industries may lower their ability to utilize each other's R&D results. We next assume that one is located in downstream industry and another in upstream industry. A firm does not lose to its partner any part of its profits which are generated by its own R&D. Partners, however, can get benefit from each other's R&D. Because partners are not located exactly in the same industry they cannot, however, get full benefit from a partner's R&D. According to these assumptions $\alpha_i = 1$ and $0 < \gamma_i < 1$ when $i, j = A, B$ and $i \neq j$.

Suppose that during isolation …rms prefer high e¤ort to low e¤ort, which implies that (5) is valid. But inserting $\alpha_A = 1$ into condition (4) also produces condition (5), which shows that in vertically integrated structure …rms choose high e¤ort with all values for the intensity of cooperation. Maximizing …rm A's utility

$$U_A^H = p_A^H U(1) + p_B^H U(v\gamma_A) - e_A^H$$

with respect to v would yield $v = 1$: That is, cooperation with maximal intensity is preferred. It is obvious that high e¤ort equilibrium now dominates low e¤ort equilibrium (with $v = 1$): Taking into account the fact that $p_A^H = p_B^H$ and $p_A^L = p_B^L$, condition $U_A^H > U_A^L$ has the expression

$$(p_A^H - p_A^L)U(1) + (p_A^H - p_A^L)U(\gamma_A) - (e_A^H - e_A^L) > 0. \qquad (26)$$

This inequality proves that cooperation of non-competitiors combined with risk-averseness can lead to high e¤ort and fully intensive cooperation even under circumstances where high e¤ort under isolation is not chosen; compare condition (5) with condition (26). Cooperation bene…ts the …rms in the setting considered owing to two reasons. First, it makes it possible to utilize the complementary nature of R&D results and, secondly, cooperation leads to portfolio diversi…cation, which generates cost-savings. If …rms were be risk-neutral, the latter bene…t would vanish. This result is much in accordance with the earlier results obtained by Steurs (1995), who states that inter-industry spillovers stimulate R&D investments, because the competitive e¤ects are lacking.

5 Two discoveries and one product

In the literature the cooperation is most often seen as a case where the partners aim at an innovation in the same brand (see e.g. Stenbacka and Tombak, 1998). We next discuss the case in which two …rms make discoveries independently of each other, but both discoveries aim at the same innovation. This innovation creates very similar products, wherefore the model considered is called a one-product model as distinct from the two-product model discussed in previous sections. Because there only is one product in the market, a …rm falls into competition in the market of a new product, if both …rms have success in R&D research. Competition arises even if …rms do not cooperate in R&D. If only one …rm is successful, the fortunate …rm grabs all the pro…ts generated by the innovation. In cooperation the profits generated by innovation are shared. We again make a simplifying assumption according to which the total profits are of equal size in the monopoly and in the duopoly.

In the one-product case there is duplication of efforts when both firms have success. In that respect the one-product case differs from the two-product case. In the one-product model a firm benefits from its partner's higher effort only if cooperation is intensive enough. Furthermore, in the one-product case the rise of cooperation intensity does not enlarge profits so powerfully as in the two-product case. The benefits of cooperation do not appear to be as large in the one-product case as in the two-product case.

In the one-product setting considered there are four states defined by probabilities of success. If firm A succeeds and B fails, with the probability $P_A(1 - P_B)$, firm A is assumed to get profits of the amount $(1 - v) + \alpha_A v$. A parameter α_A describes A's ability to capture the total profits when profits are shared. If firm A is more effective than its partner in the product market, $\alpha_A > \frac{1}{2}$. In this section we consider a symmetric case only. Wherefore it is assumed that $\alpha_A = \frac{1}{2}$. We still assume that firms can share an innovation with various intensities.

Firm A's profits in the setting considered are

$$U_A = p_A(1 - p_B)U(1 - v + \alpha_A v) + p_B(1 - p_A)U(v\alpha_A) + p_A p_B U(\alpha_A) - e_A. \quad (27)$$

If both firms succeed, firm A gets $\alpha_A(1 - v) + \alpha_A v = \alpha_A$. It is still assumed that efforts can be either high or low. When high effort is exerted $p_A = p_A^H$. If effort is low, $p_A = p_A^L$.

It is remarkable that in the one-product model considered, the firms also prefer, due to risk aversion, more intensive cooperation to slight cooperation, given the efforts. This is proved by differentiating U_A from (27) with respect to v which results in $\frac{\partial U_A}{\partial v} > 0$.

The conditions which say whether it pays firm A to deviate from high effort state $(e_A^H; e_B^H)$ is of the form

$$\begin{aligned} &(1 - p_B^H)(p_A^H - p_A^L)U(1 - v + \alpha_A) - p_B^H(p_A^H - p_A^L)U(v\alpha_A) \\ &+ p_B^H(p_A^H - p_A^L)U(\alpha_A) - e_A^H + e_A^L \\ >\ & 0. \end{aligned} \quad (28)$$

Condition (28) describes the same phenomen as condition (4) in the two-product model of section(2). Also, condition (28) is invalidated if cooperation is intensive enough. Therefore, it is obvious a cut-off value v^c for v exists such as in the two-product model too.

Suppose that firms can observe each other's effort. This corresponds to the case in which the signal discussed in section (3) is fully informative so that probabilities $k = q = 1$. In this case there is no moral hazard problem and the firms can also contract on efforts. Firms can set severe punishments which eliminate all the deviations from contracted effort level. Firms then choose between low and high efforts. Because of risk averseness the intensity of co-operation is always set on the maximal level, which is one.

Let $\tilde{U}_A^H$ denote now A's utility when $e_A = e_A^H$; $v = 1$ and $e_B = e_B^H$. $\tilde{U}_A^L$ still denotes A's utility U^A when $e_A = e_A^L$; $v = 1$ and $e_B = e_B^L$. In the case considered $\tilde{U}_A^H > \tilde{U}_A^L$ if

$$(-p_A^L - p_B^L + p_A^H + p_B^H + p_A^L p_B^L - p_A^H p_B^H)U(\alpha_A) - (e_A^H - e_A^L) > 0. \qquad (29)$$

Due to symmetry $p_A^H = p_B^H$ and $p_A^L = p_B^L$. From inequality (29) it is seen that the larger p_A^H and p_B^H, and smaller p_A^L and p_B^L increase the left-hand side of (29) and thus ease those conditions under which high effort is chosen.

The main result of this section concerns the differences between one-product and two-product cases when efforts are perfectly monitored. In the two-product model of section (3) a possibility for co-operation eases those conditions under which high effort is chosen. So a high effort equilibrium is always attained when efforts are observable (so that $k = q = 1$) and when a firm is indifferent between high effort and low effort under isolation($v = 0$). This result does not hold in the one-product case.

Proposition 5 *In a one-product case the firms do not necessarily choose high effort and intense cooperation although the partner's efforts are observed and although they would be indifferent between high and low effort under isolation.*

Proof. We prove that condition (28) with $v = 0$ does not necessarily imply condition (29). If this implication holds it would require that

$$(2U(\alpha_A) - U(1))(p^H - p^L - (p^H)^2 + p^H p^L) - U(\alpha_A)p^L(p^H - p^L) > 0.$$

The above condition is not necessarily valid. If U is linear it is certainly invalid. The validity of the above inequality also presupposes besides the strict concavity of U that p^L is very small in relation to p^H. ■

It is remarkable that in the one-product model considered it is possible that a …rm would not deviate from high e¤ort equilibrium under isolation, but would not choose a high-e¤ort contract under intense co-operation when e¤orts are observable. Why is the elimination of morald hazard in the case concerned not su¢cient for high e¤ort? Firstly, low intensity con…rms condition (28) but higher intensity does not necessarily strengthen condition (29). In other words, in the one-product model the more intensive co-operation does not increase gross pro…ts more in the high-e¤ort state than in the low-e¤ort state. In fact, the marginal bene…ts from a …rm's own higher e¤orts are strongly reduced by a partner's higher e¤orts. One can say that in the one-product model the bene…ts of diversi…cation are necessarily largest when both …rms' e¤orts are high. In any case, however, the …rms choose maximal intensity of cooperation, which is $v = 1$, if e¤orts are observable and therefore contractable also. If …rms cannot agree on high e¤orts, then lower e¤orts are chosen.

6 Public subsidy

Consider a public entity which subsidizes a …rm's R&D. If real, cost-generating R&D e¤orts cannot be observed, there is a moral hazard problem which makes public subsidy ine¢cient in raising …rms' R&D intensity. We assume that a public entity which make subsidizing decisions can monitor a …rm's e¤ort with the same accuracy as a …rm's partner. Let u be the subsidy rate. Then total subsidy is ue^H, if e¤ort e^H is observed. Because e¤orts are not, however, observed directly, a subsidy decision must be based an observed signals. It is assumed that, if a high signal is observed then the total subsidy is of the amount ue^H, whereas, if the signal is low, the subsidy is ue^L.

From this it follows that if …rm A sets $e_A = e_A^H$, s_A^H is observed by a public sponsor. Then the subsidy is ue^H. When $e_A = e_A^L$ s_A^L is observed with probability k, and s_A^H with probability 1 ¡ k. In that case the subsidy is $kue^L + (1$ ¡ $k)ue^H$. Because of subsidies cost di¤erence e_A^H ¡ e_A^L are replaced by $(1$ ¡ $ku)(e_A^H$ ¡ $e_A^L)$. Through monitoring the costs from high e¤ort can thus be lowered in relation to low e¤orts, although the gross bene…ts from high e¤ort stay untouched.

The subsidies can, for example, make an isolated …rm, with $v = 0$, to exert high e¤ort when condition (5) is invalid so that incentives without subsidies are not strong enough for this. Subsidies can also make condition

(12) valid with all v. An analysis in previous sections showed that if there exists high e¤ort equilibrium with $0 < v \cdot 1$; the intensity of co-operation is set on maximal level. So, at the best, subsidies can encourage …rms to set high e¤orts and, in addition, to cooperate intensively so that the positive externality of cooperation is internalized. In the model considered subsidies with monitoring have no real e¤ect, if the incentives for high e¤orts and intensive cooperation are strong enough without subsidies.

7 Conclusions

We consider the R&D cooperation decisions of the risk-averse …rms. The …rms are assumed to agree in advance to share R&D results but not R&D costs. In the basic case the real R&D expenditure is unobservable, which creates a moral hazard problem. The …rms contract, at the …rst stage, on the intensity of cooperation and, at the second stage, on the research e¤ort. Moral hazard weakens the …rms' motives to invest in R&D during cooperation. But diversifying the portfolio of R&D projects through cooperation increases …rms' utility. It turns out that in the absence of monitoring the …rms choose either high e¤ort and low intensity of cooperation or alternatively low e¤ort and maximal intensity of cooperation.

We also allow …rms to monitor a signal which tells more or less perfectly the partner's real e¤orts in R&D. If this signal is accurate enough, moral hazard can weaken to an extent that risk averse and independent …rms choose high e¤ort and maximal intensity of cooperation, even if they were indi¤erent between high e¤ort and low e¤ort in isolation.

It is also shown that asymmetries between the …rms reduce the scope for cooperative agreements. A …rm is reluctant to cooperate with a …rm which is more e¤ective than itself in utilizing new knowledge. Respectively, other …rms would like to cooperate with a …rm which is very e¤ective in creating new knowledge. But such a …rm would require that its partner would also meet the same e¢ciency standards in this respect.

The …rms which are located in complementary industries are not necessarily technically so close with each other, which reduces the bene…ts of cooperation. But because a …rm in another stage of a vertically integrated industry - as a client or a providor - does not compete with a partner, the moral hazard problem is more or less removed. This strengthens the incentives to cooperate in the setting considered. This phenomen is also noticed by, for example, Katsoulacost and Ulp (1998).

In the case in which two ...rms make discoveries independently of each other but both discoveries aim at the same innovation, there arises a duplication of e¤orts when both ...rms are successful. This reduces the bene...ts of cooperation, so that the conditions under which both ...rms choose high R&D e¤orts and fully intense cooperation are much stricter than in the case where the innovations aim at di¤erent products. Due to risk-averseness, the ...rms can also bene...t from cooperation in this case. The diversi...ed portfolio of R&D projects can, at its best, make the ...rms invest heavily in R&D and cooperate closely with each other.

Public authorities can make the admitted subsidy or loan dependent on the ...rms' success or, alternatively, on some evidence of the R&D exerterd. In this way public authorities can remarkably decrease moral hazard, which for its part promotes cooperation between independent ...rms at the high level of R&D.

8 Literature

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