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Abstract

The impact of asymmetries between partners on the stability of R&D cooperation is assessed analytically in a supergame setting. Two asymmetric firms are repeatedly taking sequential R&D and production decisions, whereby they coordinate their R&D decisions, in order to maximise joint profits.
The asymmetries are specified in terms of absorptive capacity (i.e. size of the spillovers), R&D efficiency (i.e. ability to implement know how) and productive efficiency or market size (i.e. net demand intercept).
First of all, it is shown that these asymmetries may not be too large, in order to guarantee that the disadvantaged firm remains interested in joining an R&D cooperative agreement. Furthermore, each asymmetry is shown to make the advantaged firm more inclined to stick to the cooperative outcome (than in the symmetric case), while the reverse holds for the disadvantaged firm. Finally, these asymmetries, when occurring simultaneously, mutually reinforce each other. All in all, R&D cooperation between asymmetric partners will typically be beneficial for the advantaged firm and will only be attractive for the disadvantaged firm if the asymmetries are not too large.

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INTRODUCTION

The profitability and stability of R&D cooperation has already been analysed by a number of authors (e.g. Dasgupta & Stiglitz (1980), Spence (1984), Katz (1986), d'Aspremont & Jacquemin (1988), Levin & Reiss (1988), De Bondt & Veugelers (1991), Kamien et al. (1992), Veugelers & Kesteloot (1994), Kesteloot & Veugelers (1995)) but most often these problems have been studied in a setting of symmetric firms. A few exceptions include Sinha & Cusumano (1991), dealing with the incentives to engage in cooperative ventures in case of complementarities, Chaudhuri (1994), focusing on technological asymmetries, and De Bondt & Henriques (1995), analysing the impact of asymmetric R&D spillovers on strategic R&D investments.

A considerable, and growing, number of alliances are established between asymmetric partners (e.g. Harrigan (1988), Veugelers (1993)). The asymmetries may relate to the nationality of firms, to the size of the home market and the degree of productive efficiency: e.g. alliances between (large) multinational firms and (small) local partners, to the experience with engaging in alliances, to the nature of product market competition among partners and between the partners and the venture, or to the degree of technological competence and efficiency, which may be reflected in the capacity to absorb and integrate own and partners' know how, or to learn from partners (spillovers). For instance, it is sometimes argued that Japanese firms are better able to transfer technological know how into marketable products than their European or American rivals.

The impact of partner asymmetries on the profitability and stability of R&D cooperation remains largely unexplored in the literature, despite its empirical relevance. Harrigan (1988) finds on the one hand that strategic alliances between asymmetric partners, possessing complementary resources and managerial capabilities, are likely to be more successful than alliances between identical firms. On the other hand, asymmetries may be harmful for venture performance, since heterogeneity exacerbates the differences in how firms evaluate the venture's activities (Harrigan (1988)). The expected benefits of R&D cooperation, and hence their willingness to participate, may differ between large and small firms. Small firms may fear being exploited by large partners. For instance, the small semiconductor firms largely stayed out of Sematech, a joint US industry-government research consortium, because of the large membership dues and suspicion that the large firms would dominate the research agenda (The Economist, April 2nd, 1994).

Based on the empirical findings that partner asymmetries tend to occur more frequently in research alliances than in other alliances (Veugelers (1993)), this paper focuses on the impact of partner asymmetries on the profitability and stability of R&D cooperation in an analytical framework. The incentives for large versus small firms to join a cooperative agreement and to stick to the cooperative outcome are investigated. Such an analysis may lead to a better understanding of the geographical, industry or product settings under which R&D cooperation is more likely to occur, or to persist.

The problem is modelled in a supergame framework whereby two asymmetric firms repeatedly take sequential R&D and production decisions, with the R&D decisions being coordinated in order to maximise joint profits. In our setting, following the empirical finding that research alliances occur relatively more frequently through coordination than through separate entities (Veugelers (1993)), R&D decisions are coordinated and firms undertake innovative efforts in their own research lab and R&D coordination is sustained by grim trigger strategies (Friedman (1971)). An accompanying paper (Veugelers & Kesteloot (1995)) deals with stable cooperation among asymmetric partners in a two-stage setting (one-time sequential R&D and production decisions) with another form of cooperation, i.e. where the two firms face the opportunity of jointly developing a new product by setting up a joint venture (i.e. a separate entity), with the alternative being own development.

FRAMEWORK

Model structure

An asymmetric duopoly, where firms produce differentiated products, with constant marginal costs c_i is envisaged. Demand for their products is:

$$p_i = a_i - bq_i - dq_j \qquad \forall\, i \neq j = 1, 2 \qquad (1)$$

where p_i (q_i) is firm i's price (quantity) and $b>0$, $b \geq |d|$.

Firms can improve their profitability by undertaking investments in R&D, which lower their production costs and which may entail positive spillovers on the rival's cost.

If no R&D is undertaken, unit production costs are $c_i=A_i$ ($i=1,2$ and $A_i<a_i$). Production costs may be reduced through own R&D efforts, as well as through the rival's R&D. Incremental innovations, yielding improvements in the production process, rather than drastic innovations, are envisaged. The importance of the spillover effect is captured through the parameter $ß_i$, which reflects the extent of such technological leakage as well as the capacity to absorb this externally generated know-how:

$$c_i = A_i - \alpha_i(x_i + ß_i x_j) \qquad 1 \geq ß \geq 0 \qquad (2)$$

$ß_i$ is assumed to be technology-specific and is exogenous. It reflects the level of automatic, uncontrollable know-how spillovers. The parameter α_i reflects the ability to apply and implement know how, i.e. to transfer know how into cost savings.

Innovative efforts involve diminishing returns, specified as increasing marginal costs of R&D. Total R&D costs are $\tau x_i^2/2$, whereby τ is inversely related to the efficiency of the innovation process.

All of this allows to specify firms' total profits, V_i, as follows:

$$V_i = \pi_i(q_i,q_j) - \tau x_i^2/2$$

$$\text{with } \pi_i(q_i,q_j) = (p_i-c_i)q_i = [a_i-A_i+\alpha_i(x_i+\beta_i x_j)-bq_i-dq_j]q_i \qquad (3)$$

Firm asymmetries

Our model incorporates size and technological asymmetries between partners. Other forms of asymmetries are ignored to keep the model tractable (cf. infra). In order to simplify the notation and to focus on the asymmetries, an s-vector is introduced, whereby the elements of the vector reflect the size of the asymmetries. To fix ideas, the 'advantaged' firm is labelled as the big (B) firm, while its partner is identified as the small (S) firm:

$$s = (s_a, s_\beta\ s_\alpha) \qquad (4)$$

$$\text{with } s_a = (a_S-A_S)/(a_B-A_B)$$

$$s_\alpha = \alpha_S/\alpha_B$$

$$s_\beta = \beta_S/\beta_B \qquad \text{with } 1 \geq s_a,\ s_\beta \text{ and } s_\alpha \geq 0$$

In case all s-parameters are equal to 1, both firms are symmetric.

Size asymmetries in terms of market size (a_S versus a_B) and in terms of production costs (A_S versus A_B) are reflected by the parameter s_a; s_a is smaller than one, reflecting that the small firm faces a smaller net demand intercept than the big firm, which may be due to lower demand for its product and/or higher production costs. Firms may differ in 'size', because of differences in consumer demand for their products, or in initial production costs. The latter may differ because of former production and innovation experience, because of organisational characteristics of the firm, ...

Furthermore, firms may differ in their technological capabilities, which is captured by two different parameters. s_α reflects the difference in *R&D efficiency*; $s_\alpha<1$ implies that the big firm can better implement all know how, or put alternatively transfer any R&D input into R&D outputs (cost savings) than its small partner, e.g. because its R&D process is managed more efficiently, because of a closer interaction between its R&D and production departments, because it has accumulated more innovation experience (learning effects) or attracted better researchers, because its production infrastructure allows to fit in process improvements more easily (De Bondt & Henriques (1995)).

Firms can not only differ in their ability to implement any know how, but also in their ability to assimilate know how from other firms. s_β represents this asymmetry in spillovers, or *absorption capacity*; $s_\beta<1$ implies that the large firm is better able to absorb foreign know how, or put alternatively, is better able to keep its own know how proprietary than the small rival, e.g. because of the nature of R&D projects, because of the firm's ability or willingness to learn from rivals, or because of luck.

Strategies

Firms play this innovation and production game for an infinite number of periods. While an infinite horizon is not very plausible, this framework applies also if the game is played for a finite number of periods, but with unknown end date. Empirical research reveals that few alliances (only 5%) determine a fixed end data when setting up an agreement (Veugelers (1993)).

During every period, firms decide on R&D and production sequentially. Each stage of the game is thus composed of a two-stage game in R&D and output, which is repeated infinitely. In order to focus exclusively on the stability of R&D cooperation, it is assumed that firms want to establish a cooperative equilibrium in R&D only, while they continue to compete in output markets (Cournot-Nash), an assumption which can be supported by antitrust legislation. It is assumed that R&D does not carry over across periods, e.g. because of the speed of technological progress or short product life cycles, which allows to apply the supergame framework.

The stability of such cooperative agreements is investigated in a setting, where the equilibrium is supported by (noncooperative) grim trigger strategies (Friedman (1971)). Both firms start out in the cooperative phase. If one firm deviates from the cooperative outcome, both firms revert to the punishment phase from the next period on, for all remaining periods of the game. If this punishment is severe enough, i.e. if foregone profits, due to the punishment, offset the initial profit increment from deviating, it will prevent firms from defecting in the first place. Hence, a stable cooperative outcome exists.

By sticking to the cooperative equilibrium, firms realise cooperative profits (V_i^c) for an infinite number of periods. The net present value of this flow of profits is $V_i^c/(1+1/r_i)$, with r_i the interest rate for firm i.[1] Given that its rival is loyal, a firm may go for maximal profits by deviating from the cooperative outcome. Defection profits are indicated by V_i^d ($V_i^d > V_i^c$). Such a defection will be punished, by reverting to the Nash equilibrium, whereby both firms realise punishment profits V_i^n ($V_i^n < V_i^c$). Given that detection and consequent punishment are assumed to take one period to unfold, the net present value of profits realised with cheating are $V_i^d + V_i^n/r_i$.

A cooperative outcome will be stable, if the following inequality holds for each firm:

$$V_i^c(1+1/r_i) \geq V_i^d + V_i^n/r_i \quad (5)$$

$$\text{or } (V_i^c - V_i^n)/(V_i^d - V_i^c) \equiv r_i^* \geq r_i \quad (6)$$

If inequality (6) is satisfied for each firm i, i.e. if each firm's interest rate is lower than a certain firm-specific threshold (r_i^*) a stable cooperative equilibrium exists.[2]

Equilibrium

A scenario of R&D cartelisation (in the terminology of Kamien et al. (1992)) is envisaged. Firms coordinate their R&D investments, but choose their output levels independently.

[1] For simplicity, discounting within each two-stage subgame is ignored.

[2] In practice, firms may choose more severe but temporary punishments. Since the length of the punishments is endogeneous in these models, such punishment structures are not pursued here, to keep the results tractable. For other possible strategies and their (dis)advantages, see Abreu (1986) and Tirole (1988).

In the second phase of each stage game, firms choose their output levels independently, in order to maximise their own profits. This yields the following first order conditions:

$$q_i = Z_i + A_i x_i + B_i x_i \qquad (7)$$

$$\forall \; i,j = 1,2 \quad i \neq j$$

with $Z_i = [2b(a_i-A_i)-d(a_j-A_j)]/(4b^2-d^2)$

$A_i = (2b\alpha_i - d\beta_j\alpha_j)/(4b^2-d^2)$

$B_i = (2b\beta_i\alpha_i - d\alpha_j)/(4b^2-d^2)$

This same first order condition holds for any output stage of the game, i.e. independent of whether firms cooperate, cheat or compete in R&D. Obviously, the corresponding optimal output levels will be different, since the R&D first order conditions will differ, depending on the stage of the game.

During the first (R&D) phase of each game, firms determine their optimal R&D levels, taking the optimal output into account. During the cooperative phase of the game, firms choose R&D levels in order to maximise joint profits, which yields the first order conditions:

$$2bq_iA_i - \tau x_i + 2bq_jB_i = 0 \qquad \forall \; i,j = 1,2 \quad i \neq j \qquad (8)$$

Given that a rival is loyal (realises its cooperative R&D effort level), a firm may increase its profits by deviating from the cooperative innovative outcome. In this case, the defecting firm determines its private optimal R&D level, taking into account that the rival firm is loyal, which yields a FOC for the defector, which is rearranged as follows:

$$q_i = \tau x_i/2bA_i \qquad \forall \; i = 1,2 \qquad (9)$$

For the notation, it was assumed that i is the cheating firm, while j remains loyal, but with asymmetric firms, obviously the cheating incentive must also be adressed from the point of view of firm j.

A deviation triggers the punishment for the remaining part of the game. During the punishment, the noncooperative sequential (Cournot-Nash) equilibrium is established. During the R&D stage, both firms independently choose their optimal R&D levels, in order to maximise private profits. This optimisation problem yields a FOC, with an identical relationship between output and R&D as in (9) - but where again, obviously, the optimal output and R&D levels will be different, since both firms now determine their sales level in this way. R&D levels for all states of the game are summarised in appendix.

Firms will stick to the cooperative equilibrium when they are sufficiently patient, that is, if their interest rate is lower than r_i^*, being the maximal interest rate for which the cooperative outcome can be sustained with eternal Cournot-Nash punishments by firm i.

Now, it will be investigated how the partner asymmetries affect the stability of cooperation. First it is analysed whether an incentive to cooperate exists for both firms, and if so, whether grim trigger strategies suffice to prevent the partners from cheating, i.e. whether stable cooperation can be achieved. An asymmetry is judged to facilitate cooperation if it increases the maximal interest rate for which cooperation can be sustained, compared with a scenario of symmetric firms. On the basis of these findings, it can be investigated which type of R&D partner (i.e. which type of asymmetry) is best selected for succesful R&D cooperation. Finally, the impact of different simultaneous asymmetries on the stability of R&D cooperation is considered. Given the complexity of the model, the results will mainly be illustrated by means of numerical simulations, for each type of asymmetry separately (whereby everything else is supposed symmetric). In each case, the same numerical example, with a-A=100, b=2, d=1, τ=2 and varying values for α, ß, s_a, s_α and $s_ß$ will be applied.[3] The findings are compared with the symmetric setting, which was reported elsewhere (Kesteloot & Veugelers (1995)).

INCENTIVES TO ENGAGE IN R&D COOPERATION

In an asymmetric setting, it must be investigated whether each firm has an incentive to join a cooperative agreement in the first place, i.e. (i) whether cooperative equilibria exist which, for both firms, yield positive cooperative R&D, output and profit levels and (ii) whether cooperation is superior to independent conduct, i.e. whether $V_i^c > V_i^n$ for each firm i and whereby obviously $V_i^n > 0$.

Positive cooperative profits

For the large firm, the usual economic viability, second order and stability restrictions on the parameter values, applying to the symmetric case, are sufficient to guarantee positive cooperative profits (V_B^c>0), independent of the magnitude of each asymmetry, considered separately. For the small firm, this also holds in case of R&D efficiency and spillover asymmetries, but this need not be the case with substantial size asymmetries, of which a numerical example is provided in Fig. 1.

INSERT FIG 1

For many parameter values of the size asymmetry, an asymmetric cooperative equilibrium may exist, with both firms innovating and producing.[4] However, with large size asymmetries (s_a<0.2 up to 0.4, depending on the level of the spillovers), the small firm would not be willing to cooperate, because of negative cooperative profits (V_S^c<0). In case of large - symmetric - spillovers, cooperation would imply that both firms innovate (x_S^c, x_B^c>0), but would entail losses for the small firm ($V_S^c+V_B^c$ is maximised, with V_S^c<0 and V_B^c>0). Intuitively, the large market size, together with the large spillovers, implies that joint profit maximisation ($V_S^c+V_B^c$) requires performing much R&D (in order to reduce unit production costs, mainly for the large sales market) and performing these R&D efforts in the two laboratories in order to reduce the costs of R&D.[5] Obviously, such high R&D efforts may

[3] The robustness of the results has been checked for other numerical solutions, which are not reported in the paper.
[4] All parameter values imply that x_B^c, q_B^c and V_B^c > 0.
[5] This is most easily seen when ß=1, which implies that x_S^c=x_B^c, independent of the magnitude of the size asymmetry.

entail losses for the small firm, which only serves a small market (high R&D costs but low sales profits, and hence $V_S^c<0$). It may even occur that it is optimal, from this joint profit viewpoint, for the small firm not to produce/sell its product, but only to perform R&D (for the partner market); i.e. joint profits are basically maximised by serving only the largest market (and thus avoiding the detrimental competitive impact of the availability of a substitute) and by spreading the R&D efforts over 2 laboratories and thus reducing the detrimental impact of diminishing returns in R&D.

With small spillovers, cooperation would imply that the small firm closes down its facilities (joint profit maximisation implies $x_S^c=0$; $q_S^c=0$ and hence $V_S^c=0$). In this case the argument of beneficial R&D decentralisation (at least for the large firm) does not apply, because of the limited spillovers.

Superiority of cooperative over independent conduct

Besides positive cooperative profits, cooperative conduct should additionally yield higher profits than noncooperative conduct for each firm. This condition is necessary to guarantee that it is worthwhile to join the cooperative agreement in the first place for each firm. Again this condition does not pose particular problems for any asymmetry for the large firm, but it may for the small firm.[6] Fig. 2 summarises the possibilities for the above numerical example.

INSERT FIG 2

Only with fairly small *market size or production cost asymmetries* (s_a above 0.84 to 0.75, depending on the level of spillovers) will the small firm prefer cooperation over independent conduct ($V_S^c>V_S^n$). In case of more substantial size asymmetries, independent conduct is superior basically since the small firm does not perform so much R&D (which mainly benefits the large firm in a cooperative setup). The case of very large size asymmetries (s_a below 0.16 to 0.28 depending on the level of spillovers) will be ignored for the remaining part of the paper, since the small firm would even in a Nash setting, decide to close down in order to avoid losses ($V_S^n<0$).

With *asymmetric spillovers*, the potential profitability of cooperation for the small firm is critically dependent on the level of the large firm's spillover, vis à vis the degree of product differentation and the magnitude of the spillover asymmetry. The critical spillover rate is $\beta_B=d\alpha_S/2b\alpha_B=ds_\alpha/2b$, i.e. where $B_B=0$, with B_B representing the slope of the big firm's reaction curve, a critical parameter which shows up frequently in these models of strategic R&D investments.[7] Hence, cooperation is potentially beneficial for the small firm (i) in case of small spillovers for both firms[8] and (ii) in case of high β_B, only if the spillover asymmetry is not too large (e.g. $s_\beta>0.8$, or even higher, depending on the level of the spillover, in the

[6] In the razor's edge case of $B_i=0$ for both firms, $V_i^c=V_i^n$, which is an artifact of the model (see also De Bondt and Veugelers (1991), De Bondt & Henriques (1995)).

[7] A similar critical spillover rate was identified in symmetric scenarios in De Bondt & Veugelers (1991) and Kesteloot & Veugelers (1995) and in a setup with asymmetric spillovers (De Bondt & Henriques (1995)).

[8] If β_B is low, β_S has to be small too, since $s_\beta < 1$.

numerical example). Intuitively, if β_B is large, cooperation involves a lot of R&D, which mainly benefits the large firm and the small firm will only find cooperation an attractive alternative if it gains quite a lot from coordinating R&D efforts too (i.e. if it absorbs enough know how from the rival). If not (low β_S), the small firm favours independent conduct, which implies less R&D. If β_B is small, cooperation does not require substantial R&D efforts, and hence the small firm will not be better off by determining its optimal R&D efforts independently.

Similar findings occur with *asymmetries in R&D efficiency*. Cooperative conduct yields higher profits than Nash conduct for the small firm, (i) in any case, if spillovers are very small for both firms, and (ii) only if the asymmetry in R&D efficiency is not too large when spillovers are bigger (e.g. s_α>0.8 if ß=1 in the numerical example), intuitively, again because the small firm has to benefit enough from cooperation (i.e. sufficiently high α_S compared to α_B). Again, the turning point between both areas lies at $\beta_B = d\alpha_S/2b$.

Hence, according to this model, in the semiconductor industry, where spillovers may be quite large, the small firms would indeed not be interested in joining a cooperative agreement with large firms, such as Sematech, because of too low expected cooperative profits.

STABLE R&D COOPERATION

For those parameter values for which duopolistic cooperative and noncooperative equilibria exist, it is now investigated how each type of asymmetry affects the stability of cooperation, taken into account the prevention of deviations by means of a grim trigger strategy. Given that both firms have an incentive to join a cooperative agreement ($V_i^c > V_i^n$), it is analysed whether they have an incentive to stick to the agreement, i.e. whether the immediate benefits from defection ($V_i^d > V_i^c$, for one period) are outweighed by the disadvantages of the subsequent punishment ($V_i^n < V_i^c$, for all remaining periods of the game), and how this net gain from cheating depends on the type and magnitude of asymmetries. This stability issue can be discussed easily in terms of the maximal interest rate that is required for firms to stick to the cooperative outcome.

Stability for the small versus the large firm

Fig. 3 illustrates the evolution of the critical interest rate (r_i^*) for the big and the small firm, in terms of the different asymmetries and the level of the spillovers.

INSERT FIG 3

In case of *size asymmetries*, the big firm is less inclined to deviate from the cooperative agreement as its rival becomes smaller (smaller s_a) and as symmetric spillovers decrease. The reverse holds for the small firm, which is, even with fairly small size asymmetries (s_a above 0.77) not very likely to stick to the cooperative outcome (i.e. its critical interest rate decreases fast with the asymmetry), intuitively because its own benefits from cooperation are not large enough, which makes cheating more attractive (high one-time gains of V_S^d-V_S^c, combined with not so severe punishment - small V_S^c-V_S^n, since V_S^c is small).

With *asymmetric spillovers*, similar results hold, at least when the spillovers for the large firm are quite substantial (i.e. if B_B>0, implying $ß_B$>ds_α/2b, or put alternatively, if the big and small firm's R&D efforts are strategic complements - cf. Bulow et al. (1985)). In this case, cooperation is more and more likely to be supported by the large firm, as the asymmetry becomes larger (i.e. $ß_S$ smaller) while the reverse holds for the disadvantaged firm. The small firm experiences quite a strong incentive to perform less R&D than agreed, in order to reduce its R&D costs substantially, without affecting its sales drastically (since it can anyway absorb know how, from the substantial R&D efforts performed by the large rival). Again, the impact of the asymmetry on the magnitude of the gains from cooperation is the driving force behind this result. Hence, to the extent that a firm can partially control the level of its own know how that its rival can absorb (i.e. its rival's spillover rate), this suggests that the advantaged firm should be aware of the fact that unilaterally keeping its know how as proprietary as possible (i.e. enhancing the spillover asymmetry) is likely to result in a breakdown of cooperation, because its small partner is stimulated into cheating. With modest spillovers for the large firm (B_B<0, i.e. if for the big firm R&D efforts are strategic substitutes), the results are reversed. In this situation, the advantaged firm is more likely to defect as the asymmetry grows larger. With low spillovers, cooperative R&D efforts are quite small, and since it does not learn a lot from its small partner, the large firm is tempted to defect by performing more R&D than agreed, in order to enhance its own sales and profits (more R&D, which does not benefit the rival much anyway, because of low $ß_B$ and $s_ß$).

With *asymmetries in R&D efficiency*, the stability issue can be described along the same lines, since a similar process is at work and is not further discussed here.

Typically, it is thus the case, at least when spillovers are large enough, that the large firm will be more inclined to stick to the cooperative outcome as any kind of asymmetry grows larger, i.e. as its rival becomes more disadvantaged, while the reverse holds for the small firm, intuitively because the large firm has more to gain from cooperation than the small firm. For the small firm, the immediate gains from cheating (V_S^d-V_S^c) decrease as it becomes more disadvantaged, while the drawbacks from cheating (V_S^c-V_S^n) decrease even faster with the size of the asymmetry for parameter values for which a cooperative equilibrium exists. The reverse holds for the large firm, which experiences less incentive to cheat as the asymmetry grows, because the immediate cheating gains (V_B^d-V_B^c) reduce, while the punishment becomes relatively more severe (V_B^c-V_B^n increases).

Since the disadvantaged firm is not very likely to stick to the cooperative outcome for any kind of substantial asymmetry, it can be concluded that cooperation is not very likely to persist between partners that differ drastically in terms of either (geographical or product) market size, productive efficiency, absorption capacity or R&D efficiency and this analytical finding is supported by the evidence since ventures between similar partners (in terms of culture, asset size, venturing experience, ...) seem to last longer (Harrigan (1988).

To the extent that the results from our model can be interpreted from the point of view of selecting an attractive R&D partner, these results imply that R&D cooperation would better be pursued with an advantaged, rather than a disadvantaged partner because such cooperation is more likely to persist (i.e. critical interest rate is quite high), while cooperation with a disadvantaged partner would be more likely to break down (or more precisely: not to materialise), because of the attractiveness of cheating for the latter. Hence, if a firm faces a choice of several potential partners, a partner with a more favourable position, in terms of size, R&D efficiency and/or absorption capacity, would be a better choice than a disadvantaged partner, at least from the point of view of stable cooperation. This issue of stability should be weighed against the gains from cooperation however, since typically an individual firm's cooperative profits are higher in case of cooperation with a disadvantaged partner, intuitively, because a more advantaged partner realises larger cooperative profits!

Sensitivity to the different asymmetries

It can further be analysed how sensitive the stability of R&D cooperation is to each type of asymmetry. Table I shows how each firm's critical interest rate responds to a given variation in each asymmetry (each s-element varying from 0.85 to 1), in a (numerical) setting where everything else is identical.

Table I: Sensitivity of stable R&D cooperation to asymmetries (α_B=β_B=0.8)
(maximal interest rate in %)

	size asymmetry		spillover asymmetry		R&Deff. asymmetry	
s	r_B^*	r_S^*	r_B^*	r_S^*	r_B^*	r_S^*
0.85	213	25	223	19	203	11
0.9	163	47	170	43	163	35
1	96	96	96	96	96	96

For the advantaged firm, the incentive to stick to the cooperative outcome is more or less identical for each kind of asymmetry - in any case its real interest rate will be below its r_B^*, but the disadvantaged firm's optimal strategy is more sensitive to the type of asymmetry. Growing asymmetries in R&D efficiency are most likely to entice the small firm to deviate from the cooperative outcome (largest decrease in r_S^* for a given asymmetry), while augmenting size asymmetries are least likely to stimulate the small firm into cheating. All of this would suggest that asymmetries in size are less harmful for stable cooperation in R&D than asymmetries in R&D efficiency or spillovers. To the extent that 'size' can be interpreted as an industry characteristic, while R&D efficiency and absorption capacity are more firm-specific, the above finding would provide an analytical justification for Harrigan's (1988) observation that industry characteristics are far more important for the stability of cooperation than firm characteristics. This interpretation should be taken with caution however, since it may be that the results are not robust, when e.g. partner firms do not cooperate only in R&D but also in output markets, or when the asymmetries generate synergies among the partners, thereby enlarging the gains from cooperation..

Several asymmetries

Obviously, if the asymmetries would occur simultaneously, they would reinforce each other.

Table II: Stability with simultaneous asymmetries
(maximal interest rate in %)

s	0.85	0.9	0.95	1
r_B^*	733	400	203	96
r_S^*	-	-	22	96

- no stable outcome

For a numerical example where the three asymmetries vary simultaneously from 0.85 to 1 (i.e. parameter values for which a stable cooperative outcome was possible for each asymmetry considered separately), each firm's critical interest rate was calculated and it is obtained that once the asymmetry is larger than 5% in all areas simultaneously (i.e. $s_a = s_\alpha = s_\beta < 0.95$) the small firm would never stick to the cooperative outcome. Hence R&D cooperation becomes infeasible, even with small asymmetries in different areas. Likewise, the incentive for the large firm to stick to the cooperative outcome is strenghtened as the asymmetries occur simultaneously: r_B^* increases to 733% when $s_a = s_\alpha = s_\beta = 0.85$ whereas it increases to a little over 200% in case of one asymmetry only - but in each case, the large firm is very likely to stick to the cooperative equilibrium (i.e. $r_B < r_B^*$).

Table III: Critical discount factor with several asymmetries
(maximal interest rate in %)

Scenario	r^* with symmetry	r_i^* with 5% asymmetry	r_i^* with 15% asymmetry
spin-off firm	96	150	285
partner	96	64	16
best researchers firm	96	186	488
worse partner	96	43	-
local partner	96	108	132
multinational	96	92	89

Finally, one partner need not be disadvantaged in all areas. A size disadvantage can e.g. be accompanied by an advantage in R&D efficiency. For instance, a spin-off firm, a small enterprise set up by researchers, may not yet have built a strong market base (size disadvantage), but may enjoy stronger technological expertise both in applying know how (advantage in R&D efficiency) and in absorbing external know how (spillover advantage) than the partner firm. In such a situation, the numerical simulations show that the spin-off firm will be more inclined to stick to the cooperative outcome as all asymmetries increase, while the reverse holds for its partner. The stability advantages associated with higher R&D efficiency and absorption capacity outweigh the disadvantages of smaller size.

If one partner is able to attract better researchers than its rival, this will lead to higher R&D efficiency and absorption capacity (higher α and β). The advantaged partner, with the better reseachers, will be more inclined to stick to the cooperative outcome, while its partner is more tempted to deviate as the asymmetry augments (fast decrease in r_i^*).

A locally operating company may consider R&D cooperation with a large multinational enterprise. The latter may for instance enjoy a size advantage, while the former may be better placed to apply know how, because of its superior information about the local conditions (no asymmetries in spillovers assumed). In such a scenario the local (multinational) firm will be more (less) inclined to cooperate as both asymmetries grow larger, because R&D efficiency asymmetries are more influential than size asymmetries.

Finally, the analysis also suggests that a scenario whereby one partner is disadvantaged in several areas vis à vis its partner is much less likely to result in stable cooperation than a scenario where the asymmetries are distributed across partners, which tends to support the empirical finding that cooperation is much more likely to be stable between partners with complementary skills (Harrigan (1988)).

CONCLUSIONS

When the asymmetric scenario is compared with the symmetric case, the following conclusions can be drawn regarding the robustness of the symmetric set up.

The symmetric setup was sufficiently rich to point out the crucial impact of the level of spillovers - vis à vis the degree of product differentiation - on the gains and stability of R&D cooperation. This characteristic, unsurprisingly, also shows up in the asymmetric setting, and additionally, it was shown that substantial asymmetries in spillovers may render R&D cooperation unprofitable, at least for the disadvantaged firm. Moreover, the numerical examples revealed that the critical level of the other asymmetries for which R&D cooperation turns out to become more or less attractive is very often related to the degree of spillovers.

Contrary to the symmetric case, the asymmetric scenario has pointed out the crucial impact of asymmetries in market size and/or initial production costs (i.e. the net demand intercept) and R&D efficiency on the expected gains from cooperation. Whereas market size, initial production costs and R&D efficiency only affect the level of profits, but not the stability of cooperation in a symmetric setup, they both have a much more substantial impact once asymmetries are incorporated. Large asymmetries (low s_α or s_a) may lead the disadvantaged firm to prefer independent over cooperative R&D conduct and large size asymmetries could furthermore result in losses for the disadvantaged firm.

All in all, intuitively, this simple analytical scenario suggests that R&D cooperation between asymmetric firms will typically be beneficial for the advantaged firm, and will only be attractive for the disadvantaged firm if the asymmetries are not too substantial, i.e. if cooperation does not benefit its partner too much more than itself.

Obviously, in order to achieve a fuller understanding of the impact of firm asymmetries on the formation and performance of strategic alliances, much more work still needs to be done. For instance, in our model it was assumed that both partners are horizontally related (they operate in the same product market), since the empirical research shows that the majority of alliances is established between horizontal partners (e.g. Ghemawat et al. (1986), Harrigan (1988), Veugelers (1994)). Nevertheless alliances between partners that are vertically related or that produce independent products may pose specific problems (e.g. larger heterogeneity and hence coordination costs) and opportunities (e.g. no product market rivalry and hence less threats to the stability of the cooperative venture) for cooperation, which are worthwhile to investigate.

Furthermore, in our model, incremental innovations, generating cost reductions, were envisaged. In practice, however, a number of innovations have a drastic character and this may fundamentally affect the expected profits, but also th persistence of strategic alliances. Therefore, it would be interesting to further investigate the incentives for cooperation aiming at the development of new products (e.g. Chaudhuri (1994)) or at improving the quality of exisitng products (e.g.Beath et al. (1987) and Poyago-Theotoky (1995)).

Also the incentives for cooperation in other organisational formats, e.g. in joint ventures, whereby the joint venture's products may likewise be horizontally, vertically or not at all related to the parents' products, should be addressed separately. This was attempted in another paper (Veugelers & Kesteloot (1995)). In this paper, also the impact of complementarities between firms, whereby cooperation will yield synergies, is studied in detail. It must also be investigated to what extent the results would be altered if the asymmetric firms do not cooperate only in R&D, but also in output markets (i.e. full cooperation).

Finally, in practice, the partners may also differ in their venturing experience and hence reputation as an attractive alliance partner, but fully investigating this topic would require a truly dynamic model.

APPENDIX: EQUILIBRIUM R&D LEVELS

From the first order conditions for the different stages of the game:

- during precompetitive R&D coordination:

$$q_i = Z_i + A_i x_i + B_i x_i \qquad \forall\, i,j = 1,2 \quad i \neq j$$

$$\text{with } Z_i = [2b(a_i - A_i) - d(a_j - A_j)]/(4b^2 - d^2)$$
$$A_i = (2b\alpha_i - d\beta_j\alpha_j)/(4b^2 - d^2)$$
$$B_i = (2b\beta_i\alpha_i - d\alpha_j)/(4b^2 - d^2)$$

$$x_i = 2bq_iA_i/\tau + 2bq_jB_j/\tau \qquad \forall\, i,j = 1,2 \quad i \neq j$$

- during cheating by firm i:

$$q_i = Z_i + A_i x_i + B_i x_j \qquad \forall\, i,j = 1,2 \quad i \neq j$$

$$x_i = 2bq_iA_i/\tau \qquad \forall\, i = 1,2$$

- during the Nash punishment:

$$q_i = Z_i + A_i x_i + B_i x_i \qquad \forall\, i,j = 1,2 \quad i \neq j$$

$$x_i = 2bq_iA_i/\tau \qquad \forall\, i = 1,2$$

the expressions for the equilibrium R&D levels can easily be derived (for i, j = 1,2 and $i \neq j$):

$$x_i^c = \frac{(A_iZ_i + B_jZ_j)(\tau/2b - A_j^2 - B_i^2) + (A_iB_i + A_jB_j)(A_jZ_j + B_iZ_i)}{(\tau/2b - A_i^2 - B_j^2)(\tau/2b - A_j^2 - B_i^2) - (A_iB_i + B_jA_j)^2}$$

$$x_i^d = \frac{A_iZ_i}{(\tau/2b - A_i^2)} + \frac{A_iB_i}{(\tau/2b - A_i^2)} x_j^c$$

$$x_i^n = \frac{A_iZ_i\,(\tau/2b - A_j^2) + A_iB_iA_jZ_j}{(\tau/2b - A_i^2)(\tau/2b - A_j^2) - A_iA_jB_iB_j}$$

Equilibrium sales and profit levels can be obtained from these optimal R&D levels. They are not reported here, beceause their complex expressions do not provide any additional insights. The second order and stability conditions (cf. Henriques (1990)) were checked for all numerical examples.

Fig. 1: Cooperative profits for the small firm, with size asymmetries

($\alpha=1$, $s_\alpha=1$, $s_\beta=1$)

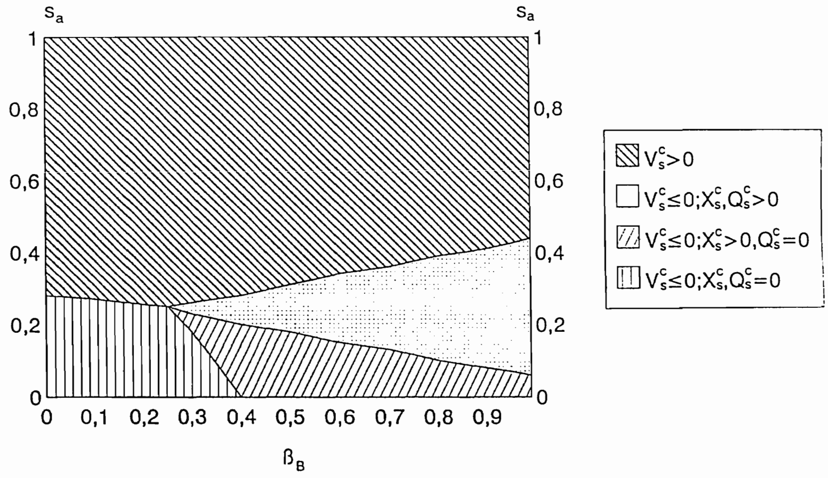
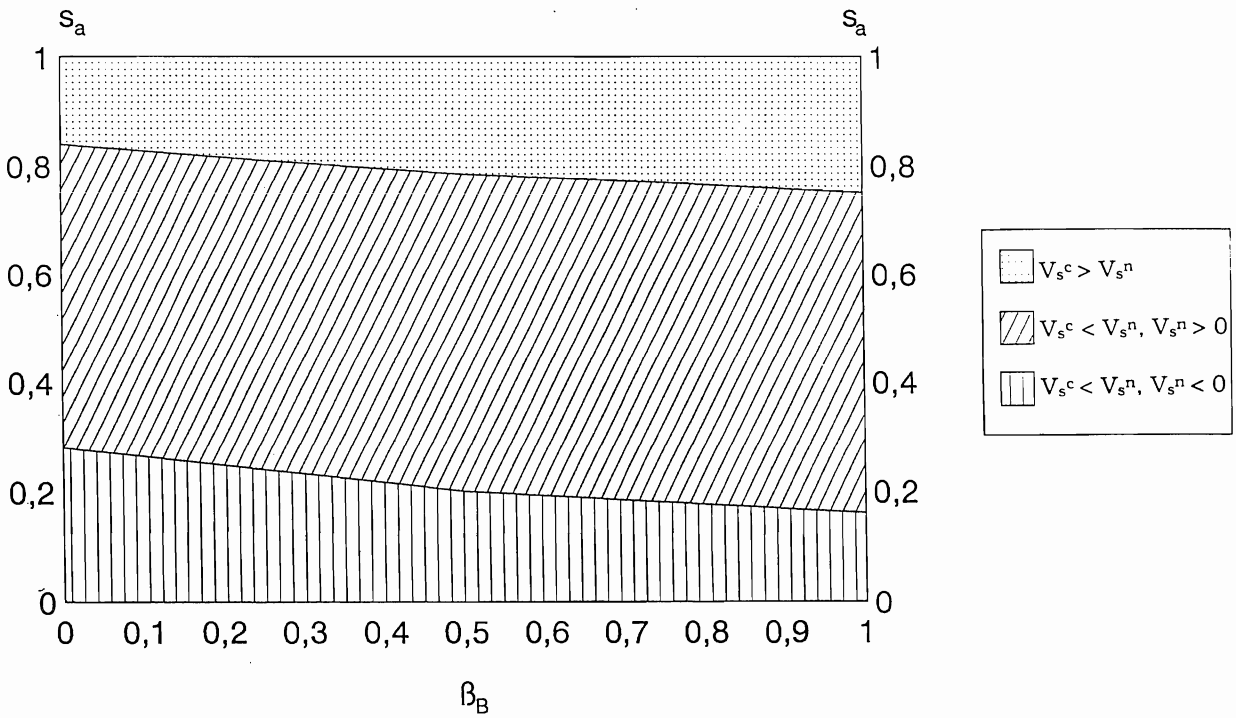
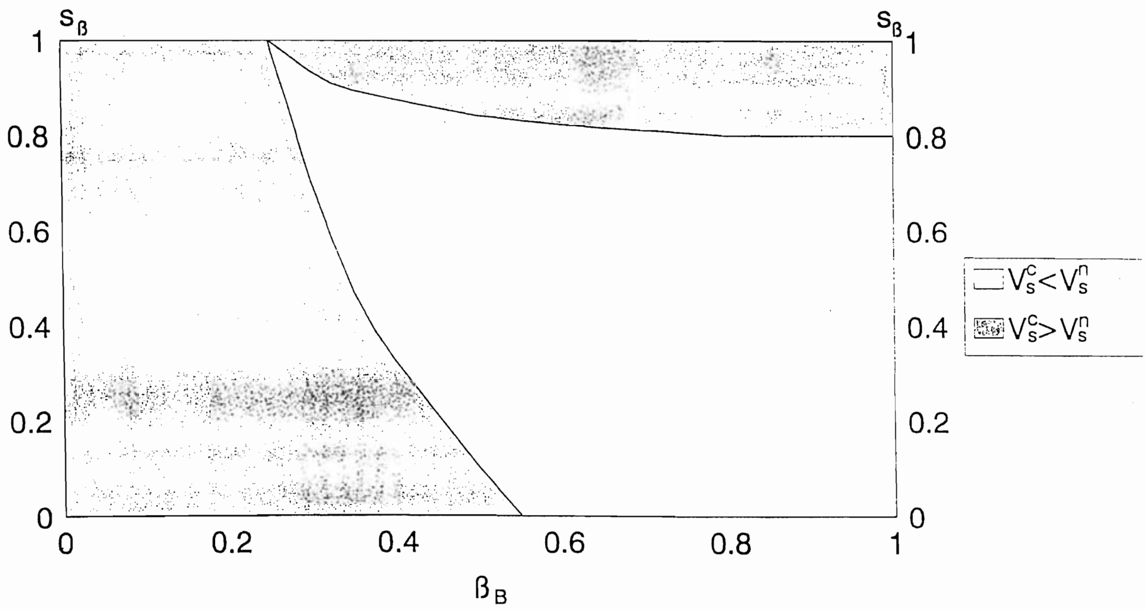


Fig. 2: Cooperative versus Nash profits for the small firm
for different asymmetries (α=1)

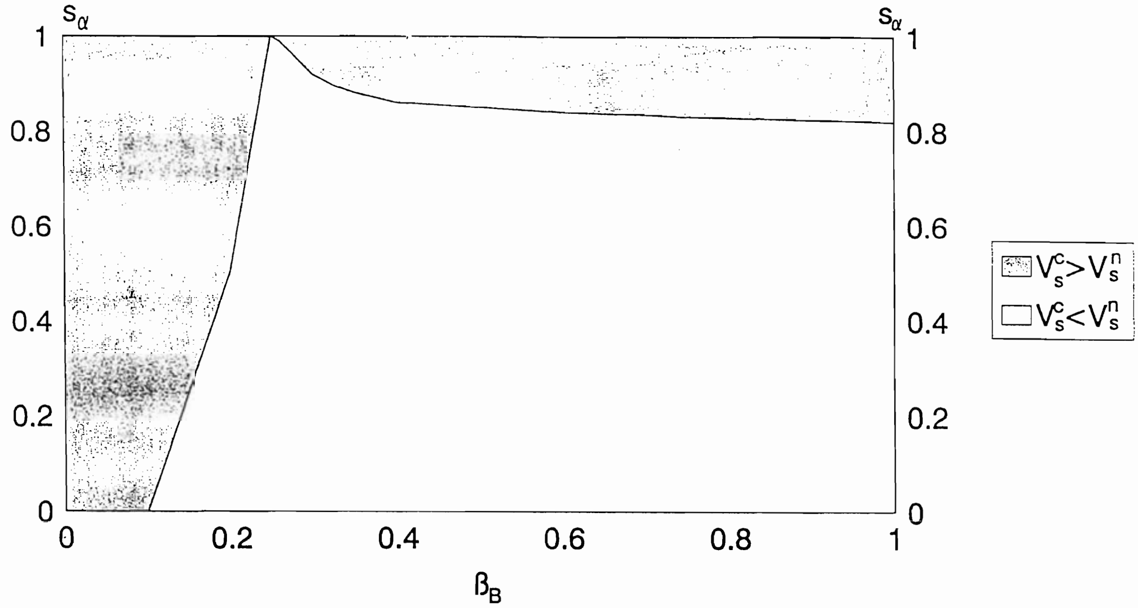


(a) Size (s_α=1, s_β=1)



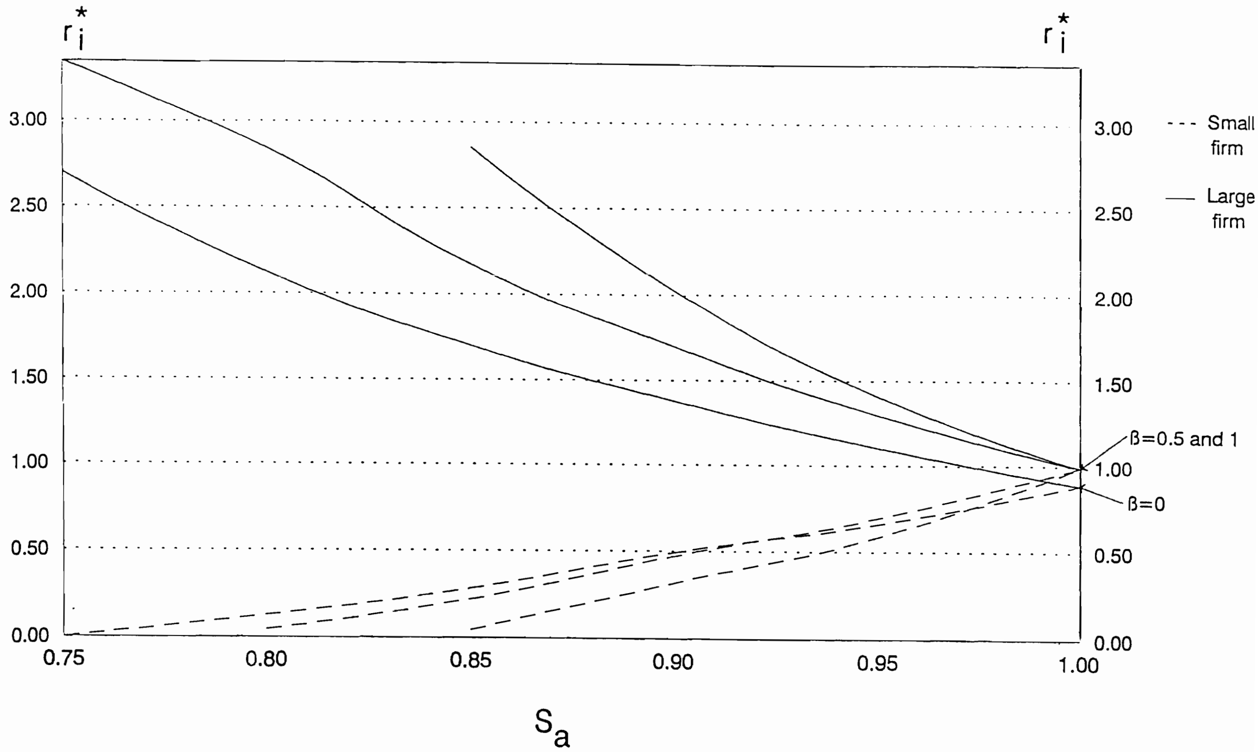
(b) Spillovers (s_α=1, s_a=1)

Fig. 2 (Cont.): Cooperative versus Nash profits for the small firm for different asymmetries (α=1)

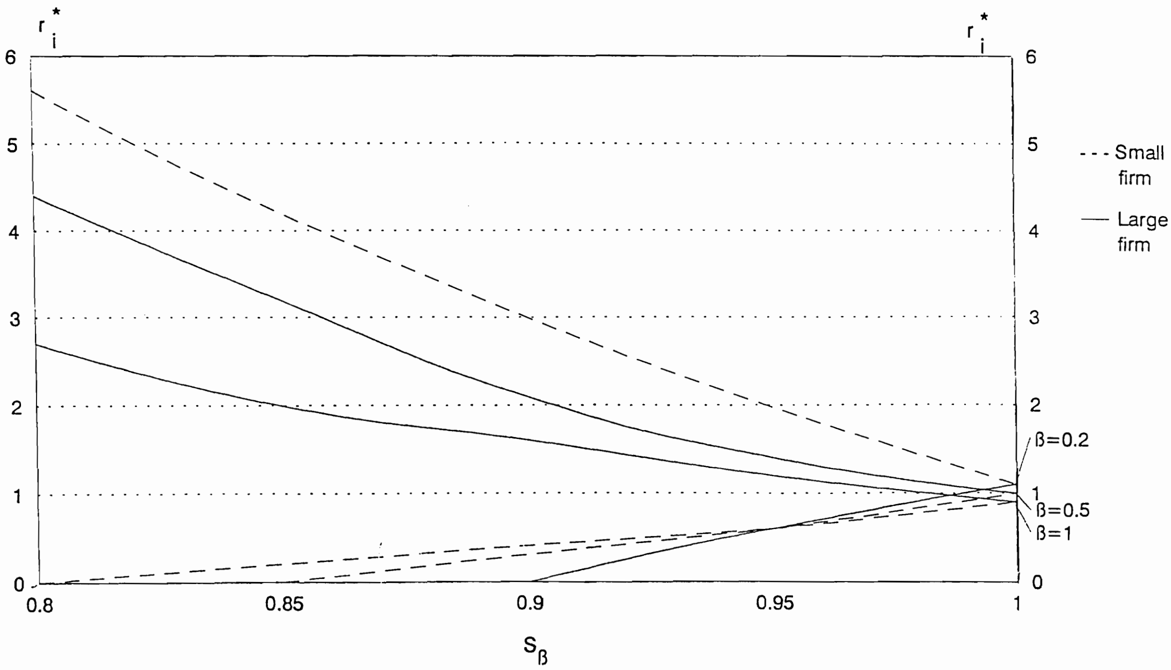


(c) R&D efficiency (s_a=1, s_β=1)

Fig. 3: Stable R&D cooperation with different asymmetries, (α=1)



(a) Size (s_α=1, s_β=1)



(b) Spillovers (s_α=1, s_a=1)

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