GAME THEORY AND THE LOGIC OF R & D STRATEGIC ALLIANCES*

SHYAMA V. RAMANI*

*Visiting Faculty, IIM Bangalore, India.

Address for Communication: Chargee de Recherche, Unit Sociology and Economics of Research and Development, Institut Nationale de la Recherche Agronomique, BP 47, 38040 Grenoble Cedex 9, France.

**An earlier version of this papesr was presented at the FPM and Research Workshop at IIM Bangalore. Revised version received in April, 1995.

ABSTRACT

According to economists game theory is the study of strategy, or study of actions of agents whose outcome depends on the actions of other agents. The objective of this paper is to outline the major contributions of game theory to an examination of the individual rationality of firms that causes them to seek and implement R&D alliances. We examine the answers proposed by the recent literature (since 1985) to two questions of importance: under what circumstances should a firm prefer an R&D strategic alliance to in-house development? how should an R&D strategic alliance be successfully implemented?

GAME THEORY & THE LOGIC OF R&D STRATEGIC ALLIANCES[1]

1.0 Organizational options for technology creation

New technology may be either acquired or created. The acquisition could be through natural technological spillovers or through a market purchase of a patent, a license, technical know-how or even a firm. Creation could be in-house or through a strategic alliance with other firms. An R&D strategic alliance can be defined as a relationship between firms, research institutions, financial institutions or other economic agents, that is constituted for the purpose of jointly creating process or product innovations. It is different from a market transaction in that it involves joint control of resources (capital, personnel, information or a product) for an agreed upon period of time.

The planning horizon of a firm, considering an investment in an R&D project and anticipating to be the technological leader may be divided into four stages: (i) undertaking investment in basic research; (ii) developing an appropriate product for the market; (iii) launching the product as monopolist and (iv) competing as a duopolist or oligopolist as others independently create or acquire the innovation. An R&D strategic alliance is distinct from an alliance formed for some other objective in that it involves some form of cooperation in stages (i) or (ii) which may or may not be continued to the product market level. Cooperation could take the form of sharing of costs, sharing of information or some form of 'cartel' behavior whereby decisions are taken to maximize joint profits of the members of the alliance rather than that of individual firms.

The types of R&D strategic alliances (RDAs from now on) commonly studied by economists are given below:

(I) Cost Sharing Cartel (CSC): one where firms cooperate only to share costs. Here firms decide on their R&D expenditure to maximize the joint profits of the group without sharing information or working together on the project. Such an alliance would be applicable to any R&D effort where there is a deterministic relation between the magnitude of R&D expenditure and the result[2]. An example would be a research consortium for a cost reducing process where the cost reduction is an increasing function of the R&D expenditure. Here the advantage provided by the alliance is the possible benefit rendered to firms through maximization of joint profits[3].

(ii) Information Sharing Agreement (ISA): one where firms share information on the results of the R&D endeavor but choose their R&D expenditures to maximize their individual profit. An example would be a research contract, say between a university and a firm, where the firm decides on its R&D subvention and the university decides on its effort input, both for their own individual profit maximization. Such sharing of information could lower costs during the development stage through the complementarity of the information supplied and the non-duplication of R&D effort.

(iii) R&D cartel (RDC): one where firms choose their R&D expenditure and share information during the research effort to maximize the joint profits of the group. In addition to the advantages of the above organizational forms, under research cartels, firms might be able to consider projects which otherwise might have rejected due to lack of a sufficient capital base or risk posed by the project. A research cartel could create a positive externality or synergy, through sharing of information, group learning, coordination and complementarity of inputs. These change the expected profit through a reduction of the investment period or the magnitude of expenditure over the investment period.

(iv) R&D joint venture (RJV): one where firms choose their R&D expenditure, share information during the research effort and also decide upon the price or quantity of the final innovation to maximize joint profits. Thus the R&D joint venture prolongs cooperation from the research level to the product market level in a legally acceptable form. In addition to the advantages rendered by the other alliances, under a R&D joint venture the commercialization strategy may be strengthened due to economies of scale, scope, logistics or procurement, a tighter appropriation of new results, a better diffusion of R&D results, and the erection of market entry barriers.

On the other hand, any RDA involves amplification of the two problems inherent to an R&D endeavor within a firm namely: 'information sharing' or 'adverse selection' and 'coordination of effort' or 'moral hazard' because it extends the network of strategic interaction. Firms may not share information because it may make their competitors stronger on the product market. They may give incomplete information on their characteristics (such as cost functions, competence) in order to spend less on R&D and 'free ride' on the efforts of others. Secondly, the firms may not honor their commitments on cost sharing. Detection of cheating ex-post may lead to inefficient functioning or dissolution of the alliance. Finally, coordination at the research level might stifle individual creativity, flexibility, entrepreneurship and prolong the investment period through manipulation.

In economics, very few formal models on RDAs seem to have been developed before 1985[4], perhaps because alliances as a mode of technology creation has gained major ground only since the 1970s, and that too in particular high-tech sectors[5]. Thus restricting our attention to the recent literature, the objective of this paper is to present for the consideration of students and practitioners of management, the major contributions of game theory, to an examination of the individual rationality of firms that causes them to seek and maintain in a particular form an alliance, given a particular state of the environment. An attempt is made to understand the relationship between the nature of technology, the market forces and the net flow of profit under the various possible organizational forms for creating new technology.

But what is game theory and what role does it serve in a management journal? According to economists game theory is the science of strategy or interdependent decision making. While 'strategy' as taught in management schools under 'strategic management' refers to long term or global planning of a firm, in game theory it refers to an action whose impact or result depends on the actions of other people or agents (such as firms, government or other institutions). Starting from this base, the jargon and methodology of game theory and strategic management tend to be very different. However in the context of RDAs they have both looked at the two fundamental questions: when should firms seek or enter alliances? How should alliances be implemented?

We thus start part 2 by examining the contributions of the game theoretic literature to the first question. Section 2.0 presents the majority of the articles that we classify in group I: Katz (1986), Bozeman, Link and Zardkoohi (1986), Grossman and Shapiro (1987), d'Aspremont and Jacquemin (1988), Beath et.al (1988), Katsoulacos (1988), Nakao (1989), Kamien et.al. (1992), and Suzumura (1992) that examine the link between 'leakage' of R&D effort and the decision to enter into an RDA. The leakage may be voluntary as when firms share information, or involuntary due to spillovers or weak legal protection. Sections 2.1-2.3 consists of articles that consider 'leakage' but where the emphasis is on other factors. Section 2.1 presents the articles by Marjit (1991) and Combs (1992) that explore the relation between the nature of the technological quest and the incentive to form RDAs. In section 2.2 we examine the article by Vickers (1985) who looks at RDAs as an entry deterrence mechanism. Then section 2.3 deals with the paper by Choi (1992) that examines the influence of complementarity of inputs in the R&D endeavor. We examine the question of implementation in sections 3.0 to 3.2. Section 3.1 looks at contracts as presented by Picard and Rey (1991) and Gandal and Scotcher (1993) as a means to implement an RDA; while section 3.2 studies the incentive mechanism proposed by Bhattacharya, Glazer and Sappington (1992). Finally part 4 concludes with the prescriptions offered to the strategic manager and the limitations of the various models.

2.0 Models of Group I

A model of an interactive situation as a game consists: (i) the designation of a group of agents as players; (ii) a set of actions for each player, for each time he may be called to play, comprising his strategy space; and (iii) a payoff function that associates the gain for each player of a strategy profile, where a strategy profile consists of a configuration of strategies, one for each player. The creation of new technology is considered to be the outcome of a sequential game between a group of firms in a market where each firm has to make two choices in the following order: strategy for technology in the form of a R&D investment; strategy for commercialization in the form of the final price or quantity to be sold. Ex-ante predictions are made by supposing that the set of likely and stable outcomes of this sequential game is the set of Nash equilibria of the game. A Nash equilibrium set of strategies (Nash (1951)) consists of a strategy profile, such that no player has any incentive to deviate from his equilibrium strategy, given that the others are playing their equilibrium strategies. In the absence of informational constraints, the Nash equilibrium (or set of equilibria) of a sequential game can be found by the method of backward induction. In other words, we look for the best commercialization strategy for each firm or the Nash equilibrium in commercialization strategies, for every possible configuration of technology strategies of the firms. And then we search for the best technology strategy or the Nash equilibrium in technology strategies under different organizational modes for technology creation.

2.0.1 Non-Stochastic Case

Consider a market with n firms, i=1,2,3,...,n with identical cost functions. Each firm i, faces a demand curve that is a function of the quantity produced by the firm, q_i, the quantities produced by other firms $j \neq i$, q_j, and a substitutability parameter γ, determining the degree of competition, a real number from the interval (0,1). For instance when $\gamma=0$ each firm is a monopolist in separated markets and when $\gamma=1$ the firms compete in the same market.

Firstly, each firm i decides on the R&D expenditure x_i. The R&D expenditure x_i results in a certain reduction in costs of $g(x_i)$. The function g is non-negative, twice differentiable, increasing and strictly concave indicating that returns to R&D investment are subject to decreasing returns. When each firm spends on R&D and experiences a reduction in costs, there is a spillover effect whereby each firm learns from the innovations or cost expenditure of other firms without any side payment. Due to the spillover effect each firm i experiences an additional reduction in costs equal to $\beta.(\sum_{j \neq i} g(x_j))$, where β is the spillover parameter, a real number from the interval (0,1). When $\beta=0$ there is no spillover and when $\beta=1$ there is complete spillover. The reduction in costs may further depend on the scale of production.

At the marketing stage, the commercialization strategy is fixed in the form of quantity to be sold q_i or price p_i to be charged (i.e. by Cournot or Bertrand competition).

Assuming Cournot competition, we can compute the Nash equilibrium quantities and R&D expenditures by backward induction as follows. Let x_j represent the vector of R&D expenditures of firms j other than i. For any possible vector of R&D expenditures $\{x_i$ i=1,2,...n$\}$, the appropriate quantities to be produced are found by maximizing the second stage profit function π_i over q_i as:

$$\pi^* = \underset{\{q_i\}}{Max}\, \pi_i(q_i, q_j, x_i, x_j, \gamma, \beta)$$

Let $q^*_i(x_i, x_j, \gamma, \beta)$ i=1,2,...,n be the solution to the problem or the profit maximizing quantities to be sold by the n firms for the given structure of the market when the firms spend x_i i=1,2,...n on R&D.

Then at the R&D level, the vector of optimal R&D expenditures of firms will depend on the institutional mode of technology creation chosen. Under in-house development each firm i, chooses its research expenditure x_i to maximizes its own profit $\pi_i{}^*(x_i, x_j, \beta, \gamma)$. This is also termed as the 'R&D competition' model since each firm competes to maximize its own gains. Under a CSC, each firm i chooses its R&D expenditure x_i to maximize the sum of the final profit $\sum_i \pi_i{}^*(x_i, x_j, \beta, \gamma)$. With an ISA the R&D expenditures x_i are calculated to maximize individual profit $\pi_i{}^*(x_i, x_j, \beta, \gamma)$ but firms share information i.e. $\beta=1$. Under a R&D cartel the firms coordinate their research efforts ex-ante, share information (i.e. $\beta=1$) and decide on individual R&D expenditures x_i so as to maximize joint profits $\sum_i \pi_i{}^*(x_i, x_j, \beta, \gamma)$. Under a R&D joint venture both R&D expenditures x_i and quantities q_i are decided to maximize total profit $\sum_i \pi_i{}^*(x_i, x_j, \beta, \gamma)$[6].

Since rational firms are assumed to choose the institutional option that yields the maximum profit, economists have studied the profit pattern $(\pi_i(q^*_i(\cdot), q^*_{-i}(\cdot), x^*_i, x^*_j, \gamma, \beta))$ i=1,2,...,n) resulting under the different institutional options to understand the technology strategy of innovating firms. The assumptions made in these models (some times implicitly!) are as follows:

Assumptions:

(i) the innovation is a cost reducing process;

(ii) the size of the value of the innovation depends on the number of firms in the alliance (more firms = more R&D expenditure = more reduction in costs);

(iii) there are no market entry barriers;

(iv) the opportunity costs and transaction costs of forming the alliance are zero;

(v) there is no problem of adverse selection i.e. there is complete and credible revealing of information;

(vi) Any protection of new technology holds for an infinite period of time;

(vii) cooperation under a CSC, ISA and R&D cartel can be restricted to the level of the research market.

Now let us translate the model into numerical terms for instance by considering a simple duopolistic market with firms i=1,2 where each of the firms face a demand $f(q_i, q_{-i}, \gamma) = a - q_i - \gamma . q_j$ with $j \neq i$. Let the cost function $c_i(q_i)$ i=1,2 be constant at c and further suppose that the reduction in costs per unit of output due to R&D expenditure $g(x_i)$ is given by $x_i^{1/2}$ for i=1,2. Then the profit generated under R&D competition (in-house development) and a CSC is given in figures 1 and 2[7]. Note that a spillover is equal to one under R&D competition gives the profit generated under an ISA; while a spillover is equal to one under a CSC, gives the profit generated under an R&D cartel.

From figures 1 and 2, it is clear that when costs are coordinated to maximize joint profits, more the spillover or sharing of information, higher the profit. When costs are not coordinated it is the reverse for high levels of market competition. Thus an ISA emerges as the worst mode for high levels of competition, because when there is sharing of information at the R&D level and fierce competition at the product level, there are two problems. Sharing information maximizes technological spillovers with competitors, brings down their cost, enabling them to charge lower prices and increase their market shares. In other words, there is a negative 'competitive externality' by which the profit of an innovating firm decreases for every unit of R&D investment undertaken. Secondly, since each firm undertakes R&D investment to maximize its profit, under an ISA there is an incentive to wait for the other firm to invest in R&D rather than spend on its own, in anticipation of using the results of others. This problem also referred to as the 'free rider or moral hazard problem' leads to sub optimal investment in R&D.

Under an R&D cartel also, the 'competitive externality' is maximized since there is complete sharing of information but the 'free rider' problem is completely internalized as R&D investment is calculated to maximize the profit of the group rather than that of its

Figure 1: Profit under R&D competition

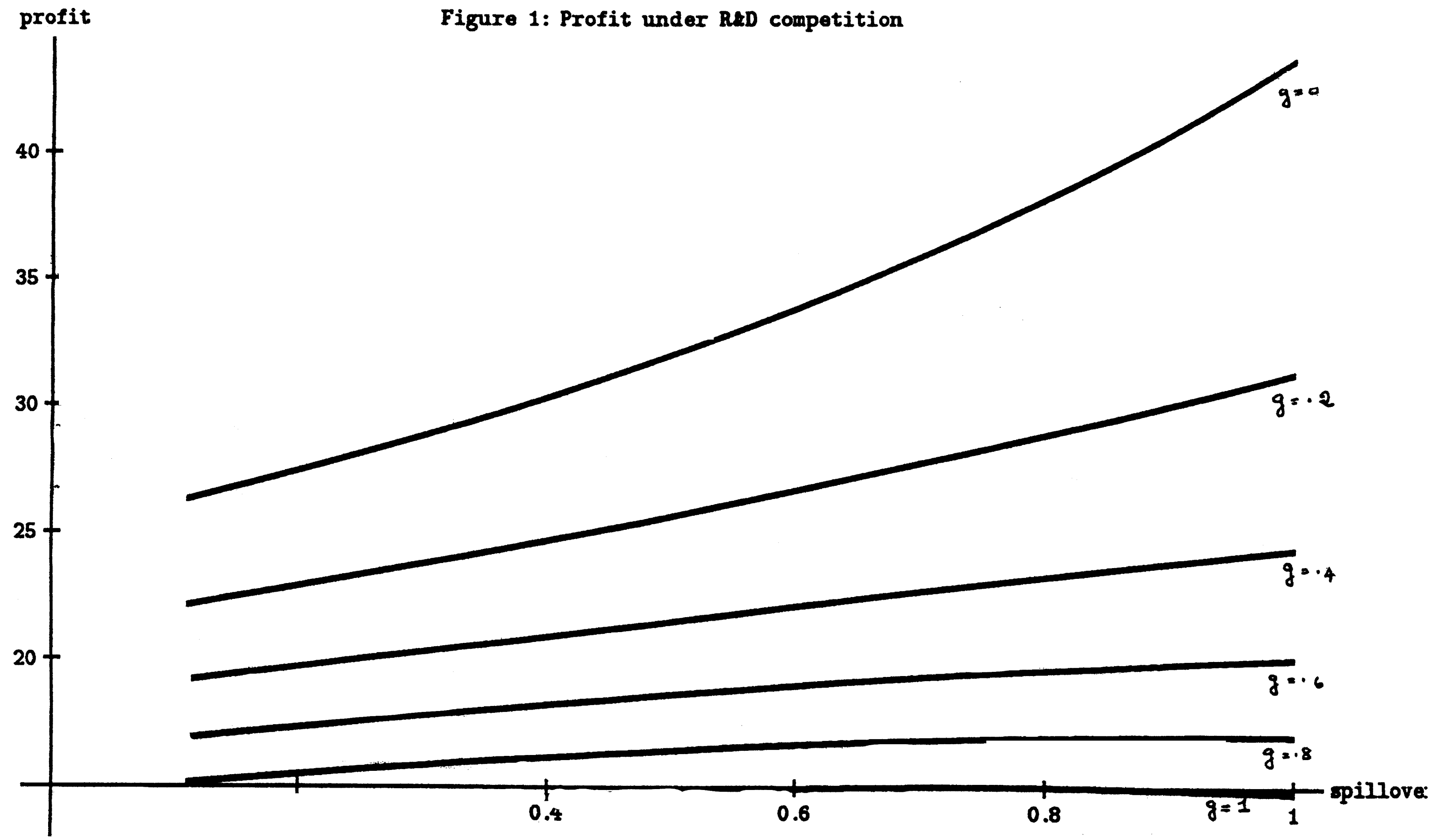
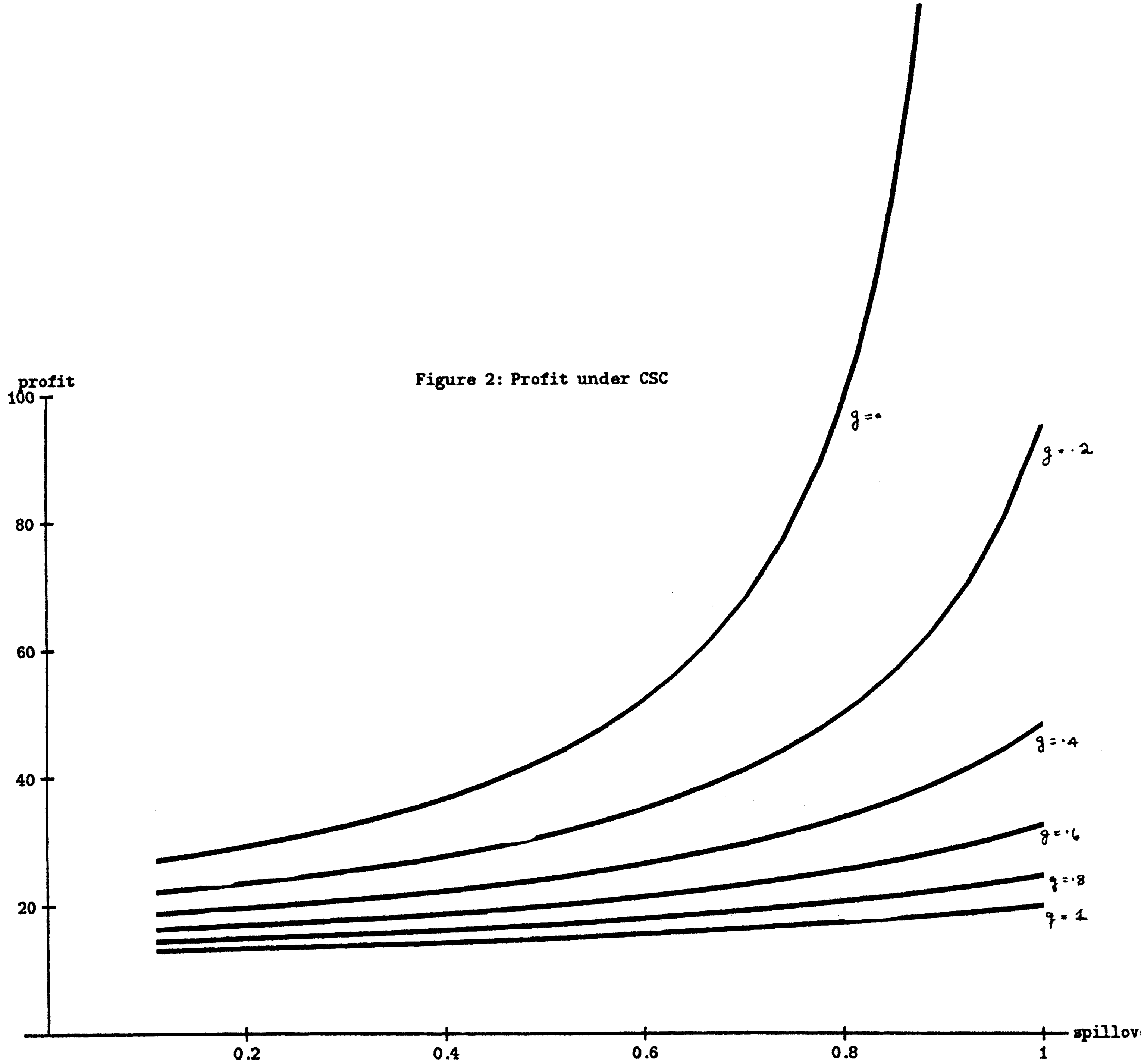


Figure 2: Profit under CSC



individual members. Given the double advantages of non-duplication of costs due to sharing of information and the internalization of the 'free rider' problem, for levels of market competition that are not too high, the R&D cartel emerges as the clear winner for firms.

This is the intuition that lies behind the models of this group. D'Aspremont and Jacquemin (1988) consider a two stage Cournot duopoly, where the spillover is constant throughout and study the relation between spillovers, R&D competition, CSC and R&D joint ventures. They consider homogeneous products and firms with a quadratic cost function. Linking spillovers with R&D investment, d'Aspremont and Jacquemin (1988) show that *when the level of spillover is sufficiently high an R&D cartel leads to higher R&D expenditure and output by the firms as compared to R&D competition.* When the level of spillovers is sufficiently low the situation is the reverse[8] (also shown by Katz (1986)). Comparing R&D joint ventures with R&D cartels, d'Aspremont and Jacquemin (1988) show that *a R&D joint venture leads to a higher level of R&D expenditure and a lower level of quantity produced as compared to R&D competition or a R&D cartel.* The R&D joint venture leads to the highest R&D investment (and profit under certain cost configurations) because not only is the 'free rider' problem internalized by completely sharing information to maximize the profit of the group, but the 'commercialization externality' is also internalized by implementing the commercialization strategy to maximize the profit of the group. On the other hand such monopolistic behavior leads to lower quantities being produced and higher prices being charged on the market. Under some cost configurations an R&D cartel and R&D joint venture lead to higher profit as well.

Kamien, Muller and Zang (1992) clearly spell out the various institutional options as adapted here, also including many firms, differentiated products, general cost function and Bertrand price competition and prove that *when full disclosure of information can be assured an R&D cartel leads to maximum research investment while an ISA leads to the* *minimum research investment* (also proved by Katz (1986)). Kamien et. al. also show that *an R&D cartel leads to the maximum profit when information sharing can be ensured.* The reason as indicated in this section is due to the internalization of the 'free rider' problem.

Nakao (1989) constructs a static model of n-firm oligopoly, where the profit depends on the conjectural variation made about how one firm responds to another firm's output and R&D expenditure decision. He thus also studies a case not mentioned above, namely when there is collusion on the product market but not on the research market. He shows that *if the product market is perfect (i.e. competitive externality is zero) then a R&D joint venture increase welfare through non-duplication of effort; however under imperfect competition a R&D joint venture could lead to under investment in R&D* .

The model of Katz (1986) is very comprehensive and contains many of the conclusions of the above papers. Katz studies a four stage game with n symmetric firms. In the first stage firms decide whether to enter into an RDA or not. In the second stage they choose how much of information to share. They also choose how much of costs to share. In the third stage each firm i decides its R&D expenditure and in the final stage each chooses the quantity to put on the market. Katz then shows that *higher the market competition lesser is the extent of the above phenomena.* When the product competition is intense the competitive externality is more, the post innovation prices are less and it is the consumers who benefit more. Therefore the firms have less incentive to invest in R&D.

Bozeman, Link and Zardkoohi (1986) present a graphical model, where the R&D expenditure is a private input that produces a public good namely knowledge (i.e. spillovers are complete). A budget constraint gives the most efficient transformations of the private good into the public good The optimum input or R&D expenditure is found by the tangency between isoprofit curves and the budget constraints. They illustrate that *more basic the research (or higher the public good characteristic of research) higher the R&D expenditure under an RDA cartel as compared to R&D competition.*

2.0.2 Stochastic case

Despite the elegance of the information sharing models, being non-stochastic, they fail to capture the intrinsic nature of technological effort namely that of uncertainty; why should R&D efforts always be successful? This last point is rectified in the stochastic models, where in the static case, when each firm i spends x_i on R&D, costs are reduced with probability p_i. In particular, p_i is the probability that firm i innovates in a small time interval, contingent on the fact that the other firms have not innovated up to that time, (also known as i's hazard rate) and it depends solely on firm i's current flow rate of R&D expenditure. Choosing a R&D expenditure is then equivalent to choosing a probability of success. Here then, an RDA increases the probability of success per unit of money spent, through coordination of research. When cost reduction is not certain, there is a possibility that some firms might manage to innovate while others do not or innovate before others do etc. Thus the contribution of the stochastic framework vis-a-vis the deterministic framework is to incorporate the notion of uncertainty, introducing a winner who can try to protect his innovation and a loser who can try to catch up by imitating.

Furthermore when the framework is changed from a one shot game to a multistage game, say a two stage game to distinguish between the stages of research and development, firms have to decide on expenditure twice. A firm might or might not succeed in the first stage, but then a loser in the first stage might be able to catch up partially with a winner in the second stage. A loser may also drop out of the race altogether after the first stage. Thus the contribution of this dynamic stochastic framework is to model the innovation effort as a marathon race, permitting different winners at different stages of the race and deal with uncertainty at more than one stage.

Then the analysis is similar to the one in the earlier section, except that the actual profit are replaced by expected profit to compare R&D competition, ISAs, CSCs and R&D cartels.

Grossman and Shapiro (1987) examine a two stage patent race, in a duopolistic market. The firms invest in research in the first stage and they develop the product in the second stage. They consider various institutional options, R&D competition, licensing, government given patents and ISAs. In their dynamic stochastic model, a firm that cannot keep up with the leader (or the most successfully innovating firm) has to drop out of the innovation race. Thus under in-house development, the leader ends up with monopoly rents. However if firms form an alliance simply at the R&D level, less efficient firms can get information on the innovation without any cost and then engage in fierce product competition with the leader afterwards, in which case the leader loses out. This leads to the fact that *firms prefer in-house development to an ISA when market competition is intense, fixed costs are high or final product prices are low.*

Beath et.al. (1988) and Katsoulacos (1988) study the effect of 'easiness of imitation' on the formation of different R&D set-ups. Here the spillover parameter β serves as an indicator of the 'easiness of imitation'. When imitation is easy β =1 and when imitation is difficult β =0. Beath et.al. examine the case when imitation is easy; Katsoulacos examines the case when imitation is difficult. They show that *when technology can be easily imitated (for instance, when the legal mechanism for protection is weak) an R&D cartel is preferred by firms to in-house development. However when imitation is difficult, the choice between in-house development and R&D cartel rests on the relative magnitudes of the monopoly rents and the alliance rents.* In these stochastic models cartelization lowers the cost per probability of success; however by sharing information, the partners of the ventures also become more aggressive competitors on the product market. When imitation is easy, under R&D competition, each firm prefers to be an imitator rather than an innovator and hence they under invest in R&D leading to low profit. Again an R&D cartel is preferred because by internalizing the negative competitive effect the under investment problem is taken care of.

2.1 Alliances due to the nature of technology

Marjit (1991) compares R&D competition with an R&D cartel in a duopolistic market where firms have the option of engaging in the development of a cost reducing innovation. The innovation is drastic, i.e. if attained by one of the firms, it makes that firm a monopolist. If both firms enter into an R&D cartel they share fixed costs and information, so that they earn the same profit. He then proves that *it is profitable to form an R&D cartel when the technological quest is such that the probability of creating the innovation is very high or very low for a set of symmetric firms.*

Combs (1992) extends the Marjit model to examine what would happen if risks were shared instead of costs. Suppose each firm had to choose a project out of 'm' projects only one of which would be successful. Then p=1/m. Further suppose that if they formed an R&D cartel, each firm could pursue a different line of research i.e. each could choose a different project. In this case, the probability of success for the R&D cartel is p=2/m. However since each firm has to maintain its lab the fixed cost is not shared but incurred by each firm. Then he shows that *if the probability of success is high then an R&D cartel would be preferable to R&D competition.*

In the Marjit model, when probability of success is high, a firm faces the risk that its rival may innovate and become a monopolist. And since it is better to be one of two duopolists than out of business, the firms collude. When probability of success is low, collusion is again desirable as costs can be shared. However since this is not the case in the Combs model, there is little incentive for the firms to collude under the latter condition.

2.2 Alliances due to complementarity

Choi (1992) considers two firms in two different industries which are trying to develop an innovation using a contractible input, like machines and a non-contractible factor, like effort. Probability of success is a function of the two factors used. The innovation of value V to each of the firms, is accompanied by a spillover of $\beta.V$. The innovating firm can license the rest through bargaining. In other words the innovator bargains over the value α, so that he gets V+$(1-\alpha).(1-\beta)$.V from the innovation. Full sharing of information occurs as the bargaining takes place under complete information. Under R&D competition each firm i maximizes its profit over the inputs taking as given the inputs supplied by its rival (i.e.Cournot behaviour in inputs). In an R&D cartel, each firm maximizes its profit over the non-contractible input for agreed values of the contractible output, taking the non-contractible input of its rival as given. He then demonstrates that *in an R&D cartel there is under provision of the non-contractible input but as the complementarity of the inputs increase the returns to the R&D cartel also increases.* The result holds because when the complementarity of the inputs is low, the moral hazard problem in an R&D cartel is very strong. For instance, firms might not want to send their brightest staff to the R&D cartel. However if the innovation yields sufficient monopoly rents and there is complementarity of inputs, this problem is overcome and an R&D cartel is preferred to in-house development.

2.3 Alliances for achieving strategic objectives

Vickers (1985) studies a situation of m incumbents, in an industry supplying a homogeneous good. An innovation of size 's' reduces the constant marginal cost of production from c to c-s. The m incumbents are joined by n potential entrants, all of whom compete for a patent for the new technology. Under R&D competition each of the m incumbents chooses 's' so as to maximize his profit if he wins the patent minus his profit if an entrant wins the patent. In an R&D cartel, the m incumbents choose a common value of s' so as to maximize the difference between their total profit if they win the patent and their total profit if an entrant wins the patent. These constitute the incentives of the incumbents in undertaking R&D expenditure. Under any set up the incentives of the entrants are different, being the profit they would earn were they to enter the market. In his context, Vickers examines the influence of these asymmetric incentives, the size of the innovation s, and the power of the rivals in terms of m and n, in promoting R&D competition or cartel. Here the incentive to form or not form an R&D cartel is compared assuming that the patent is won by the incumbents in both the cases, which is unrealistic. Thus in a second example Vickers introduces the notion of who is likely to win the patent through making the cost reduction probabilistic and then studies the incentive to form an RDA.

He concludes that *in a market with a group of incumbents who are trying to prevent a group of rivals from entering: (i) when the innovation is drastic, R&D competition will prevail and it will be more effective in preventing entry; (ii) as the size of the innovation gets smaller, an R&D cartel will be preferred to R&D competition by the incumbents and it will prevent the entry of rivals.*

When the innovation is drastic, it means that the successful firm reduces costs to such an extent that the other firms are forced to go out of business. In this case the monopoly rents to be earned are so high that the incentives of all firms, incumbent or entrant, is the same and it is each one for himself. When the innovation gets smaller, under R&D competition, entry will not be prevented because of the free riding problem that causes under investment. When a firm i manages to prevent entry by undertaking R&D expenditure all firms $j \neq i$ gain from the protected market as well and hence every firm under invests hoping that another firm will prevent entry. This problem is completely removed in a cartel which is therefore successful in preventing entry.

3.0 Successful implementation of RDAs

Even under the propitious conditions outlined in the previous section the success of an RDA is not guaranteed because by assuming away informational constraints the following implicit assumption was made :

'It is common knowledge that if cooperation is more profitable for all parties then all parties know that it is more profitable for all parties'.

In the absence of such common knowledge, some parties may be unclear as to whether cooperation is more profitable for them or perceive it to be less profitable than non-cooperation. Since beliefs are formed on the basis of information available, the main impediment to successful implementation of RDAs under favorable conditions is the *incomplete or imperfect information* of firms. These informational handicap gets translated into the following two problems in alliances:

(i) *Adverse selection* where firms false falsify or hide information on firm characteristics. For instance, Firm A might enter into an alliance with firm B believing that it offers a complementary asset, say knowledge of a particular field, and might find that firm B has nothing to offer of that kind. This can lead to problems in partner selection and negotiations on allocation of revenue from the innovation on the basis of firm characteristics.

ii) *Moral hazard* where firms cheat on commitments or firms falsify/hide information on actions implemented by them. Thus could be manifested in terms of firms in the alliance not applying enough research effort or not sharing enough the results of R&D efforts.

To tackle adverse selection it is necessary to *increase the available information* by putting in place a mechanism that forces other firms to reveal information about themselves (screening mechanisms or direct revelation mechanisms) that are credible. In order to be credible, the revelatory mechanism must be designed in such a way that it is more costly for the interested firm to lie than to tell the truth.

To solve the problem of moral hazard it is necessary to *directly influence the beliefs* of partner firms so as to make the strategy of cooperation more profitable than non-cooperation. All moves to influence beliefs also share the problem of credibility.

Two credible ways to tackle the problems posed by informational constraints are to write out contracts or put in place incentive mechanisms that make truth telling and cooperation attractive. In a repeated interaction framework such measures must ensure that *gains from cooperation take place before the gains from non-cooperation occur.*

However success is not assured even with the best of contracts or incentive mechanisms because of the problem of *verifiability* of cheating, which gets even worse as the number of players involved increase. If mistakes are perceived to be made and punishments are meted out accidentally or vice-versa the incentive mechanism may fail to save the alliance. There can be no general theory of verifiability, the problem being particular to each case concerned.

3.1 Contracts

A DRM or direct revelation mechanism consists of a set of functions, say c_i, t_i designating the R&D costs to be undertaken and the final monetary transfers to be made to firm i in an RDA. Both c_i and t_i are functions of some message m_i revealed by firm i on its characteristic, say its information or knowledge. An optimal contract or DRM satisfies the following constraints: (i) participation constraint: Firms earn more by entering into an RDA contract than through R&D competition; (ii) revelation constraint: for all true values of m_i , the payoff from reporting the true value is at least as great as reporting any other value; (iii) incentive constraint: payoff from applying the R&D effort c_i is at least as great as from any other R&D effort; and (iv) budget constraint: the sum of the transfers t_i is at least as great as the expected profit to be generated. The a priori distribution of the m_i's and the function $c_i(m_i)$ and $t_i(m_i)$ are common knowledge.

Picard and Rey (1991) look at the design of optimal contracts to achieve the socially efficient level of R&D expenditure in a coordinated R&D competition model. The problem is to implement a research project whose returns depend (in a deterministic fashion) on the R&D inputs of a number of firms. The private information of the firms or the messages m_i to be revealed are the profitability of the project for the individual firm concerned. The costs c_i's that the firms must be induced to undertake are the R&D investments. Assuming that there is perfect complementarity of inputs. such that the participation constraints are satisfied for positive returns (for then returns from R&D

competition would be zero) they show that *under some general conditions on the relation between the vector of R&D investments and the consequent results, a DRM can be constructed to induce revelation of the profitability of firms and undertaking of R&D effort to maximize the social gains from the project.* The general conditions usually pertain to the fact that returns to effort must be increasing (or in some cases at least non decreasing). This permits a minimum level of rent to be available from undertaking the R&D project which can then be redistributed so that a firm which announces a higher profitability (from undertaking investment) pays more but also gets more. Thus firms have no incentive to either exaggerate or decrease the true value of their profitability. Then they design a quadratic payoff system where a premium is also paid for committing one self to the R&D effort announced.

Scotchmer and Gandal (1993) study the problem of implementing an R&D cartel where the message m_i to be revealed is the ability of the firm. Like Grossman and Shapiro (1987) they assume that in a duopolistic market, if a larger proportion of the R&D investment can be undertaken by the firm with a higher ability, then at the social level, the of allocation of resources with an R&D cartel will be more efficient than under R&D competition. Assuming that the firm that makes the scientific discovery or design first will be granted a patent of known value, and the probability of making the scientific discovery depends on the abilities and the R&D investments of all the firms, they examine how a DRM may be constructed to maximize joint profits. They prove that *if the messages (i.e. reported abilities) cannot be verified*[9] *but the R&D investments can be verified, then a DRM satisfying all constraints can be constructed to implement any feasible set of payoffs but if both the messages and the R&D commitments cannot be verified then a DRM that satisfies both budget and participation constraints can be constructed only under certain conditions.* When abilities cannot be verified a punishment scheme may be installed to force truth telling. Then the R&D efforts can be contracted out (i.e. without any problem of commitment) and the spoils redistributed so that for every firm it pays to be part of the cartel than to pursue in-house development. However when R&D efforts cannot be contracted out, a premium must be given to all the alliance partners to induce optimal effort. However such premiums may not be feasible given the rents associated with the project. Thus Gandal and Scotchmer show that if there is a high degree of correlation between the abilities and the costs of making the discovery such that R&D costs are more determined by firm abilities than their responsiveness to incentives an optimal DRM may exist. The root of the problem is that when the efforts can not be verified, the instrument variable for governing each firm is simply the transfer variable t_i, while there are two unknowns the real value of the message m_i and the R&D effort c_i and hence the optimal contract can not be formed under all conditions.

3.2 Incentive mechanisms

Bhattacharya, Glazer and Sappington (1992) attack the moral hazard problem through the second venue developing an incentive scheme involving R&D licenses that ensure efficient signaling of information. They consider an R&D cartel in a three stage game. In the first stage, each firm realizes its knowledge as an independent realization of a random variable. It cannot exaggerate its knowledge but can disclose a part or whole of it. A firm learns from disclosures only if the knowledge level disclosed by other firms is higher than its own. The firm that reveals the most is chosen as the leader. In the second stage, each firm decides on an unobservable R&D expenditure. The resulting decrease in costs is a function of the probability of success desired, the level of knowledge of the firm and the possibility for learning from disclosures of other firms. In the third stage, the firms engage in price (Bertrand) competition.

Now the problem is how to achieve the first best outcome with every firm that entered the first stage of research also moving into the second stage of development and with complete disclosure of information on the part of the firms. For this two licensing mechanisms are proposed: UL or unrestricted licensing mechanism (unrestricted from the point of view of the leader) and RL or restricted licensing mechanism. Under UL, after the first stage, the leader decides on a uniform entry fee to be imposed on all lagging firms who wish to enter into the second stage of the game. The lagging firms can then choose to enter or not enter into the second stage. If the leader wins in the second stage, it can commercialize the innovation in the product market in the third stage. If a lagging firm or a number of lagging firms create the innovation in the second stage, one of them is chosen as the licensee. In order to sell on the product market the licensee has to pay rV to the leader, (where r from (0,1) is chosen by the leader), if it earns at least V in the product market. Under RL, the leader cannot control the number of firms entering in the second stage, but it can choose a licensee as before if any of the lagging firms succeed at the end of the R&D stage. They then prove that *there exists a value of entry fee and a proportion r such that the UL scheme ensures the first best outcome; if the equilibrium probability of success is high enough or the cost function satisfies certain properties then an RL scheme can also ensure the first best outcome.*

By construction the licensing schemes ensure first best R&D effort levels when there is full disclosure and optimal number of participants in the second stage. Under the UL scheme, there are two instrument variables provided to achieve the two objectives. With the entry fee monopoly rents are provided to the leader inducing full disclosure. Then the proportion r is fixed so as to induce optimal level of R&D effort. Dissipative competition in the third stage is prevented because the licensee pays r.V to the leader only it earns at least V in the product market. Under RL, the earning of the leader are the license royalties and any profit it makes on the product market, if it is successful in the second stage. Therefore it can earn monopoly rents and be induced to disclose knowledge, only when the equilibrium probability of success is high.

4.1 Conclusions and Limitations of the literature

In this paper we examined the contribution of the game theoretic literature on when a firm should consider forming an RDA and how a firm should successfully implement RDAs as summarized in table 1. For a strategic manager, besides offering formal proofs of intuitive observations that rents from an alliance will exceed those from in-house development if the synergy created is high, the complementarity of inputs is high, the legal system for protection of new technology is lax, or the technology can be easily imitated, the models have clearly delineated the role of 'information sharing' and 'coordination of costs to maximize joint profits'. The advantages of 'information sharing' are that they lead to non-duplication of costs, learning or creation of synergy The disadvantages are that they increase the 'competitive externality' and the 'free rider' problem. The net benefits of 'coordination of costs' is a function of the cost configurations of the firms, the demand parameters and the level of market competition. In this context, they have illustrated that while 'information sharing' alone or 'coordination of costs' alone may not achieve the highest level of profits, the two coupled together will achieve the best results under most circumstances. They have also indicated less obvious circumstances arising due to the nature of the technological quest (such as high or low probability of success) and nature of innovation (not a radical innovation, public rather than private good) that make RDAs more attractive than in-house development.

With respect to the viability of these alliances, it has been pointed out that problems of implementation arise due to insufficient availability of information, inefficient circulation of information and non-observability of crucial actions. If informational constraints can be clearly identified and if the rents from the R&D project are sufficiently high then it may be possible to envisage schemes for redistributing the rent so as to induce information revelation and application of optimal effort. An important fact that has been pointed out is that often there might be a conflict between the participation and the budget constraints, i.e. the rents may not be high enough to pay the premiums for truth telling and

Classification of Models

Models	RDAs examined	Motivations for forming RDAs	When or how to form an RDA
d'Aspremont and Jacquemin (1988)	CSA, R&D joint ventures	share information	When spillovers are high When information can be completely shared When output is a public good When market competition is not high
Suzumura (1992)	CSA		
Kamien, Muller and Zang (1992)	CSA, ISA, R&D cartel		
Nakao (1989)	R&D joint venture		
Bozeman, Link & Zardkoohi (1986)	R&D cartel		
Katz (1986)	CSA, ISA, R&D cartel	share information & costs	
Beath, Katsoulacos & Ulph (1988)	R&D cartel	share information and increase probability of success	When technology can be easily imitated
Katsoulacos (1988)	R&D cartel		
Grossman & Shapiro (1987)	R&D cartel		When market competition is not high,
Marjit (1991)	R&D cartel	share information & costs	When probability of success is high or low
Combs (1992)	R&D cartel	share information & risks	When probability of success is high
Choi (1992)	R&D cartel	complementarity of inputs	When there is sufficient complementarity
Ordover & Willig (1985)	R&D cartel	creation of synergy	When there is sufficient synergy
Vickers (1985)	R&D cartel	share information & costs and block entry	When the innovation is not drastic
Bhattacharya, Glazer & Sappington (1992)	R&D cartel	share information & learn	through licensing
Picard & Rey (1991)	Coordinated R&D competition	maximize social returns	through an optimal contract
Gandal & Scotchmer (1993)	R&D cartel	increase probability of success and minimize social costs	through an optimal contract when R&D efforts can be verified

Table 1

cooperative behavior. In this case, even if the technological and market conditions are favourable the alliance will not be successful. Thus the contribution of the literature is to give examples of informational problems (profitability of project being private information, ability of firms being a private information) and moral hazard problems due to non-observability (application of R&D effort, sharing of information) that may be surmounted through appropriate design of incentive schemes (contracts, licenses, entry fees).

At a macro level, what can be inferred from this literature for the formulation of national technology policy? Three ways by which a technology policy can stimulate the rate of new technology creation are through giving subsidies, implementing a tight intellectual property rights regime and granting lenient treatment under antitrust law. It has been shown in some of the papers (e.g. Ordover and Willig (1985), Katz and Ordover (1989), Nakao (1989)) that subsidies aggravate the monitoring and moral hazard problem, while a tight intellectual property regime leads to sub optimal diffusion of knowledge. Furthermore, there seems to be a consensus that a lenient treatment under antitrust law is a good way to promote cooperation in R&D because in many of the cases when profit from an RDA is higher than under R&D competition, R&D investment is also higher under an RDA as compared to R&D competition[10]. However there is a controversy over whether there should be general rules to evaluate the benefits and costs of R&D strategic alliances or whether there should be a case by case analysis. The above models in illustrating that the relation between the organizational mode of technology creation and the outcome for profit depends on a number of variables and the relation that exists between them, seem to favor a case by case analysis rather than any blanket rules[11].

On the other hand, besides their restrictive assumptions the models studied so far suffer from a number of drawbacks: (i) In the papers R&D efforts and objectives (except in Vickers 1985) are considered to be unidimensional whereas in reality often R&D efforts have a number of technological and market objectives that make the optimal mode of technological creation dependent on the tradeoffs between the achievement of the different objectives. (ii) Since the focus is on process rather than product innovations, in most of the papers the important problem of allocation of innovation profit among partner firms is assumed away. This is also disappointing because one of high tech areas most marked by strategic alliances for the creation of new technology, namely the biotechnology sectors, has been fueled by a number of radical product innovations. (iii) No model has comprehensively examined the role of the legal mechanisms for protection. It has been noted again and again in the descriptive literature that patent laws, licensing and royalty rules etc. have a great influence on the mode of technological creation but the particular features of the different mechanisms and their impact on alliances have yet to be formalized. (iv) An important advantage of RDAs listed in the descriptive literature is the creation of synergy through group learning but this has hardly been touched in the above models[12]. (v) Most of the papers consider only symmetric firms and industry wide research consortiums which need not always be the case. (vi) The papers on implementation do not study sharing of information, the influence of demand factors or market competition. However there are papers (e.g. Darrough and Stoughton (1989)) which have studied the problem of implementing joint ventures (for objectives other than new technology creation) through constructing an optimal DRM, incorporating some of these factors. Thus this could be a venue for fruitful research in the future.

Furthermore, while game theoretic models have been rich in examining the variety of circumstances under which an R&D alliance may be preferred, there is ample evidence that many alliances break down before yielding any substantial result (Kogut(1989)). Thus there is scope for a deeper understanding of why alliances fail. For instance, game theory is based on the assumption that economic agents are rational, which in its simplest terms means that they pursue their self interests. The guise of rationality gives ample scope for opportunistic behavior. This in turn sometimes leads to situations termed as the 'prisoner's dilemma' where the Nash equilibrium is sub-optimal for the entire group, i.e. there exists a non-Nash configuration of strategies that yields a higher payoff for all the agents in the game. Cooperation as it usually studied in game theory is about how to resolve a 'prisoner's dilemma' situation and make the optimal configuration of strategies emerge as a Nash equilibrium by changing the rules or parameters of the game[13]. In the models studied here there is no scope for opportunistic behavior. Cooperation is studied as an organizational form of productive activity rather than as a resolution of a 'prisoner's dilemma' set up. On the other hand it is likely that some of the alliances fail because the structure of the payoffs resembles a 'prisoner's dilemma' paradigm.

Secondly, under the theoretical artifacts of the models the payoff functions emerge as strictly concave functions over a convex domain giving rise to a unique Nash equilibrium configuration of strategies. In reality there are likely to be multiple Nash equilibria, in which case there must be *'coordination'* to select a particular Nash equilibrium if a Nash equilibrium is taken to be a likely outcome of the game. The coordination may be achieved through pre-play communication, bargaining or because it forms a focal point of the game. It would be interesting to study this problem if not at a theoretical level, at least through case studies for this could well be the reason for the failure of some strategic alliances,

Finally, little work has been done on the different forms of financing and their relation with the institutional options for technology creation[14]. The formation of RDAs as a means of dealing with the fast pace of technological change or the complexity of the scientific base of industries is also yet to be studied in depth.

[1] The author gratefully acknowledges the financial support of the Fondation Nationale pour l'Enseignment de la Gestion Des Enterprises and the very useful comments of the two referees.

[2]Such an alliance would not apply to any probabilistic research effort, say as in a product innovation, because in this case there will be a winner of the technological race. Unless the winner shares information or patent with other members of the consortium, there will be no benefit from fixing R&D expenditures to maximize joint profits.

[3]this in turn would depend on the market structure and competition.

[4]The pre-1985 literature mainly dealt with the different strategies or trajectories for in-house development for a firm involved in a technological race. For instance, should a firm be an innovator or an imitator?; at what point of time should the innovation be marketed?; how should an innovation be protected? etc. but they did not consider other institutional options such as alliances. See Reinganum (1984) for survey.

[5] In the second half of this century, three technological revolutions have occurred, first in the chemical industries, then in the micro-electronics industries and now still to mature in the bio-technology sectors. In the chemical industries, both technology creation and commercialization were in-house; in the micro-electronics industries alliances were found at the commercialization stage (ex. IBM and Microsoft). Now in the bio-technology industries, alliances are found at the production stage itself between small dedicated science-based biotechnology firms and large diversified firms with commercial know-how.

[6]Given that there are no informational constraints in all the cases the Nash equilibrium vector of R&D expenditures and quantities will always be credible, i.e. the Nash equilibria obtained are also sub-game perfect.

[7]These graphs were obtained using the package 'Mathematica' where a=10 and c=5. Similar results will be obtained for any a>c.

[8] The principal objective of katz (1986), d'Aspremont (1988) and Suzumura (1992) was to study whether RDAs were good were society so as to guide technology policy and antitrust laws. Suzumura (1992) extends the d'Aspremont and Jacquemin model to many firms with a more general cost and demand function. Both do not distinguish between the advantages provided by coordinated sharing of costs (e.g. CSC) and joint coordination of entire research effort (e.g. R&D cartel). Suzumura generalizes the d'Aspremont and Jacquemin welfare result to prove that when the spillovers are high, R&D expenditure under both an R&D cartel and R&D competition fall short of the first best solution; when spillovers are low, in an R&D cartel there is underspending and under R&D competition there is over spending. Thus he recommends that when spillovers are large, technology policy should encourage all forms of R&D spending; when spillovers are little, technology policy should facilitate cooperative R&D ventures and restrict competitive R&D spending.

[9]or the R&D commitments cannot be verified; this is not proved but it is mentioned that it will follow from similar arguments.

[10]This is always the case with an R&D cartel. But it is not always so for an R&D joint venture, because the net result depends on the interaction between the research market and the product market.

[11]A sizable literature on antitrust policy has stemmed from the concern of some economists that while in the recent past America could pride itself on its antitrust policy as being one of the factors responsible for high factor productivity, now the very same antitrust policy is a stumbling block to national

competitiveness in the hi-tech sectors (see Ordover and Willig (1985), Grossman and Shapiro (1986), Jorde and Teece (1990) etc.). Others such as Shapiro and Willig (1990), and Brodley (1990) disagree that the impact of antitrust law depends on a number of factors which are unique to each system and which must be studied together as a system before normative judgments can be made.

[12] Ordover and Willig (1985) who studied the impact of R&D cartels on society show that: when a RDA cartel is formed among firms with no current market power in the sectors to be affected by the R&D, it will innovate faster than under R&D competition and lead to faster product competition if:
a) the complementarity of assets results in a research efficiency coefficient higher than that of any of the firms; b) for a firm that innovates earlier than an RDA the profit from being the sole innovator is less than the profit it would have earned through being in an RDA. This is possible when the products of the ventures are complementary and lead to increase in size of market or are highly differentiated with distinct market niches. This paper was not included because while studying the impact of RDAs cartels on society, the incentives for firms to form RDAs under the conditions given was not examined.

[13]In some cases it has been shown that cooperation occurs even when there is scope for opportunistic behavior if there is a built-in incentive mechanism in the form of reputational stakes. Firms which seek to build up 'reputation' have a long planning horizon and they cooperate in order to develop or maintain a reputation for a certain type of commitment. Fudenberg and Tirole (1991) have modeled this phenomenon as an engagement in an infinitely repeated game where reputation is shown to be equivalent to a commitment to cooperation, which then emerges as an equilibrium strategy yielding the best payoffs in the planning horizon of the firm. Thus building a reputation might involve some short run losses but it is undertaken to yield long run gains. However in any finitely repeated interaction there is likely to be an incentive to cheat near the end of the interaction since there is nothing to lose anyway at the end if reputation is eroded. In this context, cooperation might be observed if the agents are not clear as to when the interaction is likely to end (Freidman (1971)).

[14]Aghion and Tirole (1994) look at the relation between a research unit and a customer, for example a small research lab and a large company which could also be a possible financier. They show that the innovation should be owned by the research unit whenever the marginal efficiency of the research unit's input is higher, whenever the ex-ante bargaining power of the research unit is higher or whenever the cash constraints of the customer are higher. They also illustrate that an initially greater ex-ante bargaining power of the customer can be counteracted by introducing a private investor, say a venture capitalist or a bank. Finally, they show that a RDA cartel, termed in their paper a research joint venture, will be preferred to a merger, whenever merging leads to a substantial fall in rents for the research unit.

REFERENCES

Aghion, P. and J.Tirole (1994). Opening the black box of innovation, *European Economic Review*, 38, pp.701-710.

d'Aspremont, C. and A. Jacquemin (1988). Cooperative and Noncooperative R&D in Duopoly with spillovers, *American Economic Review*, 78, pp. 1133-1137.

Beath, J., Katsoulacos Y. and D. Ulph (1988). R&D rivalry Vs R&D cooperation under uncertainty *Recherches Economiques de Louvain*, 54 (4), pp. 373-384.

Bhattacharya, S., Glazer, J., and D.E.M. Sappington (1990). Sharing productive knowledge in internally financed R&D contests, *The journal of industrial economics*, no.2, pp. 187-208.

Bhattacharya, S., Glazer, J., and D.E.M. Sappington (1992).Licensing and the sharing of knowledge in research joint ventures, *Journal of Economic Theory*, 56, pp. 43-69.

Bozeman, B., Link, A. and A.Zardkoohi (1986).An Economic Analysis of R&D joint ventures, *Managerial and Decision Economics*, 7, pp. 263-266.

Brodley, J.F. (1990). Antitrust Law and Innovation Cooperation, *Journal of Economic Perspectives*, 4, pp. 97-112.

Choi, J.P. (1992). Cooperative R&D with moral hazard, *Economics Letters*, 39, pp. 485-491.

Combs, K.L. (1992).Cost sharing vs. multiple research projects in cooperative R&D, *Economics Letters*, 39, pp. 353-357.

Freidman, J. (1971). A Non-Cooperative Equilibrium for Supergames, *Review of Economic Studies*, 38, 1-12.

Gandal, N. and S. Scotchmer (1993). Coordinating research through research joint ventures, *Journal of Public Economics*, 51, pp. 173-193.

Grossman, G. and C. Shapiro (1986). Research joint ventures. An antitrust analysis, *Journal of Law, Economics and Organization*, II.2, pp. 315-337.

Grossman, G. and C. Shapiro (1987). Dynamic R&D competition, *The Economic Journal* 97, pp. 372-387.

Jacquemin, A., (1988). Cooperative Agreements in R&D and European Antitrust Policy, *European Economic Review*, 32, pp. 551-560.

Jorde, T.M. and D.J.Teece (1990). Innovation and Cooperation. Implications for competition and Antitrust, *Journal of Economic Perspectives*, 4, pp. 75-96.

Kamien, M.I., Muller E. and I. Zang (1992).Research Joint ventures and R&D Cartels, *American Economic Review*, 82, pp. 1293-1390.

Katsoulacos, Y. (1988). On incentives to cooperate in R&D when imitation is difficult. a simple economic model, *Aussenwirtschaft*, 43, pp. 141-146.

Katz, M. L., (1986).An analysis of cooperative research and development, *Rand Journal of Economics*, 17, pp. 527-543.

Katz, M.L. and J.A.Ordover, (1989). R&D Cooperation and Competition, Martin Neil Baily and Cifford Winston eds. in *Brookings Papers on Economic Activity*, pp. 137-203.

Kogut, B., (1989). The stability of joint ventures. Reciprocity and Competitive Rivalry, *The Journal of Industrial Economics*, 38, pp. 183-198.

Marjit, S. (1991). Incentives for cooperative and non-cooperative R&D in duopoly, *Economics Letters*, 37, pp. 187-191.

Nakao, T. (1989). Cost reducing R&D in Oligopoly, *Journal of Economic Behavior and Organization*, 12, pp. 131-148.

Nalebuff, B. and A.Dixit (1991). *Thinking Strategically. The competitive edge in business, politics and everyday life*, W.W. Norton and Company.

Nash, J. (1950). Equilibrium points in n-person games, *Proceedings of the National Academy of Sciences,* pp. 36-49.

Ordover, J., and R. Willig (1985). Antitrust for High-technology Industries. Assessing Research Joint ventures and Mergers, *Journal of Law and Economics*, 28, pp.311-333.

Picard, P. and P. Rey (1991). Incentives in cooperative research and development, in *Essays in honor of Edmond Malinvaud,* Cambridge University Press, pp. 252-279.

Reingaum J.F. (1984). Practical implications of game theoretic models of R&D, *American Economic Review,* 74, pp. 61-65.

Shapiro, C. and R.D.Willig (1990), On the Antitrust Treatment of Production Joint Ventures, *Journal of Economic Perspectives,* 4, pp. 113-130.

Suzumura, K. (1992). Cooperative and Noncooperative R&D in an oligopoly with spillovers, *American Economic Review,* 82, pp. 1307-1321.

Vickers, J. (1985). Pre-emptive patenting, Joint ventures and the persistence of oligopoly, *International Journal of Industrial Organization,* 3, pp. 261-273.