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Spillovers and Innovative Activities

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1. Introduction

The economic analysis of innovative activities has a long history. The late sixties and the seventies saw a first wave of contributions, that were mainly decision theoretic approaches analysing the impact of existing and potential rivalry on timing of innovative ventures, using the at that time flourishing mathematical control theory (see Kamien and Schwartz (1976)).

A second life cycle of research brought a first attack of game theory on the field and this occurred during the beginning and mid eighties (see Reinganum (1989)). It resulted in a high level of sophistication in the analysis of innovative activities, with stochastic differential games investigating expenditure patterns in racing efforts and stochastic settings being employed to analyse asymmetric games in innovation, such as those played by incumbents and new entrants.

In the past ten years then, we have witnessed a third wave in the I.O. analysis of innovation, with the game theoretic analysis of spillovers in oligopoly. Spillovers refer to the voluntary or involuntary leakage of knowledge or know-how within organizations, such as firms and joint ventures as well as between creative individuals and organizations. It extensively uses multiple-stage games that often abstract from timing issues and are technically somewhat "easier" to handle than the sophisticated earlier contributions of the first and second wave of analysis.

Roughly speaking the first waves of analyses focused on the timing of introduction of innovative activities. But in a world of global economies and technological changes such as superhighways facilitating transfer of often exponentially growing information, it is likely that the challenge for players may not always be to be among the first to produce the new information, but may instead be how to recognize, obtain, employ and complement the relevant innovative information. The real challenge for firms and economies may be to recognize the resources that are necessary for the appropriate organization of innovative information activities : entrepreneurial talents, appropriate industrial and firm organizations and appropriate organizations of transfer and diffusion of technology, and of education and science activities.

The recent literature on spillovers and innovative activities has begun to shed some light on these issues and although many questions are still left unanswered, it may be worthwhile to take a short pause and try to assess where we are. It is not the ambition to review all results here, but instead the intention is to emphasize and clarify a number of points that do not seem to have received the attention they deserve.

The usual complaint against modern theoretical I.O. is that all results are too much model- or even parameter specific. For each situation there is a model, and we nowadays see scholars sometimes formulate practical recommendations on the basis of a highly specific model and a few numerical examples. For each situation we have a different explanation, but the search for robust insights seems to be out of fashion (Sutton(1992)). But spillover effects do show a certain robustness across various models, although it obviously takes some patience to discover the similarities. Still, annoying artifacts or specifics remain. Rather than to resolve those it may be better to move to different grounds: away from symmetric settings and from too simple modeling of innovative activities.

A following section provides some background on spillovers and innovative activities. The effects of symmetric spillovers on the difference between innovative efforts with and without cooperation and on performance are detailed next. Finally the attention goes to consequences of asymmetric spillovers and to urgent issues on the research agenda.

2. Spillovers

Many business strategies have to take into account the interdependencies or spillovers on the demand and production side. Spillovers hereby often refer to the side effect of the strategy. Advertising effects for one brand may spill over to other brands; a good (or a bad) experience with one product of a brand may have positive (negative) effects on other products of the same brand; innovative investments by one firm may reduce or enhance the competitiveness of a rival producer; inputs (e.g. physical or human capital) purchased by a purchasing firm may allow quality improvements or cost reductions that cannot fully be appropriated by the selling unit (Griliches (1992)).

But in many cases spillovers indicate the transmission (leakage or transfer) of useful knowledge and know how. This is a potential source of confusion. It is possibly misleading to think of such an information transmission as being synonymous of positive side effects or externalities. Research and development that improves the competitiveness of one firm may at the same time reduce the profits of a rival, even though the latter receives some useful information of the former firm that may also allow it, to some limited extent, to say reduce cost or improve quality. The strategic investment activities then inflict negative externalities on the rival even though a positive transfer of information occurs (De Bondt and Veugelers (1991)).

The intention here is to focus mainly on business strategies related to so called innovative activities and to avoid confusion, spillovers will here be equivalent to knowledge spillovers: involuntary leakage or voluntary exchange of useful technological information.

2.1. Innovative activities

Technological change, innovative and knowledge creation activities are complex phenomena and it is therefore useful to first sketch some major categories of interest here.

One stylized view is that technological change takes place as a succession of incremental changes, with occasional major shifts and discontinuities. Discontinuities are relatively rare and may both destroy or enhance the competence of existing firms in the industry (Tushman and Anderson (1986)). "Competence destroying discontinuities" require fundamentally new skills, abilities and knowledge. (e.g. plain paper copying, transistors instead of vacuum tubes, compact disks instead of records; mechanical ice instead of shipped natural ice, catalytical instead of thermal cracking, float-glass process in glass manufacturing substituted continuous grinding and polishing). They are very exceptional and unconstrained new entrants often play a major role. "Competence enhancing discontinuities" are drastic as well, but more frequent and since they build on existing know how within a product class, existing successful firms often play a major role (e.g. electrical typewriters replacing mechanical ones, the thin-walled iron-cylinder black engine, the edison kiln (cement process)).

All discontinuities may change the industry structure in a drastic way, e.g. because of the entry (and exit) they stimulate, while they are surrounded by high technological and market uncertainty. Stochastic racing models and other dynamic settings capture some essential elements including the option (potential) rivals have to stop searching and to influence timing.

But most industries are also characterized by long periods of "incremental product and process changes". These tend to consolidate and improve technologies and are competence enhancing. Even the appearance of drastic new inventions that eventually may render obsolete a technology, may in the meantime often help the older technology to realize further rents. Many of the technologies that underlay the development of the steamship, for example, actually served to enhance the efficiency of sailing ships (in 1892, 70 years after the steamships began moving trade between England and North Sea Ports, British shipyards launched their largest tonnage of sailing ships ever (Young (1993)). These and other incremental changes thus typically consolidate and stretch life cycles of existing technologies and do not stimulate drastic changes in industry structure (less entry and exit because of the changes). Symmetric or asymmetric models of cost-reducing or quality enhancing R&D investments can be expected to capture the impact of the market and technological environment on these incremental efforts. Learning by doing, diffusion and licensing models are of likewise importance, but will not be looked at here.

2.2. Technological spillovers

The described "innovative" activities clearly offer many opportunities for useful transfers to other existing and potentially new market participants. The importance of spillovers for business and for innovative activities and economic growth has recently spurred an abundant empirical literature. While the evidence points to the importance of spillovers, it also suggests important differences between industries (and countries) and between the various means of information transmission. Spillovers in other words do have a "structural" component as well, since intra-industry spillovers may be larger in industries with high technological opportunities and with similar products and fabrication processes (say automobiles, computers) (see also Jaffe (1986)). Consistent with this observation is that inter-industry spillovers tend to be smaller than intra-industry spillovers (Bernstein (1988)).

Innovations are often accompanied by export of the technologies to other areas and applications and in those activities the "entrepreneur" is essential. While not introducing the inventions for the first time, they find for example new geographic locations where inventions of others can be introduced profitably, and take the risk of adapting the exported techniques to the geographic and market conditions in the new locations (Baumol (1993)). The focus here is not on these "entrepreneurial" technology transfer activities, but rather on more or less "routinized" information transfers that also allow technology to travel with dramatic rapidity.

A widely cited study by Mansfield (1985) on the basis of 100 American manufacturing firms reports that "information concerning development decisions is generally in the hands of rivals within 12 to 18 months, on the average, and information containing the detailed nature of a new product or process generally leaks out within about a year". They also found relevant product information to typically leak out more quickly than process information. Levin, Klevorick, Nelson and Winter (1987) also looked at the cost and time required for imitation and reached similar conclusions as to the easiness of information transfers.

The new information has a tendency to become known, whether or not the creator wants to prevent it (Arrow (1962)) and the channels and mechanisms of information transfer are numerous. They include licensing technology, patent disclosures, publications or technical meetings, conversations with employees of innovating firms, possibly in the context of informal networks, hiring of employees of the innovator, reverse engineering (Mansfield (1985)).

Of interest is that also independent R&D is seen by companies as an important (sometimes the most important) channel of spillovers (e.g. Harabi (1995)). Such investments, among others, enhance the capabilities for learning about and monitoring of the latest technological trends in the market and generate more useful knowledge to be traded if so desired (Cohen and Levinthal (1989)). In addition they make it more likely that research and development activities can follow uncorrelated routes and hence that they are complementary. One camera manufacturer, for example, may figure out an improved automatic focus device, another an automatic light adjustment, and a third may invent a way to make the camera lighter and more compact. These divergent research findings create ample room for exchange of useful information, that quickly and cheaply can be incorporated in so far that existing products and production technologies are not too far apart.

Research at universities serves as a complement for company R&D, for technologies related to computers, metallurgy, materials, chemistry and biology (Nelson (1986)). Clearly such research and interpersonal contacts in technical and scientific societies and networks, further serves as a channel of technological and scientific spillovers.

Firms often take a lot of effort to arrange deliberate mechanisms of spillovers. Baumol (1993) notes, for example: "In some cases the arrangement is totally informal, each firm simply expecting full access to the innovations of the horizontal rival, with full provision of its own technological advances serving as the quid pro quo. And often, even where exchange is ex-post and involves cross licensing of specified patents from each firm to the other, the licence fee is set at zero". Also in ex ante exchanges in the framework of a research joint venture, the parties may not know in advance what they will get from the transaction since the contract gives access to innovations that will only emerge in the future.

Spillovers result from transfer and exchange of information, but they only refer to the useful part of the information that has been exchanged. Two firms may supply each other all information on whatever innovative activities they have been doing, and still the spillover may be small, for example, because their existing technologies or products are so different, or because of organizational resistance. It is important to stress that the useful employment of spillover information in itself is a real challenge for the management of innovation. In the pharmaceutical industry, for example, companies that are able to take advantage of knowledge generated in all areas of the organization are significantly more productive than their rivals (Henderson (1994)). High tech firms need the brightest people in core technologies, but they also have to work together. Even though new technologies (fax, e-mail) now facilitate new transfer of information, effective communication does not always come easy. Sometimes, say when a manufacturing innovation causes a yield breakthrough in production of memory chips, and when developed in one location, it may be adapted very quickly by other manufacturing lines. But information and learning in general does not come free, because of specialization and psychological and other barriers. One high-tech company started a "not invented here" award, giving recognition to people who adopt an idea from elsewhere in the company (Taylor (1990)). To develop a sustainable advantage may require the use of adequate knowledge management structures (e.g. pooling knowledge in semi-permanent project teams, more space in offices so that learning by walking around is stimulated, generalist training, rotation, incentive structures), or more generally, a "learning organization", that is "an organization skilled at creating, acquiring, and transferring knowledge, and at modifying its behavior to reflect new knowledge and insights"(Garvin (1983)).

3. Cooperation with symmetric spillovers

Firms' operations in an international context are characterized by an enlargement of the competitive environment, stimulated by the convergence in consumption patterns and by the technological evolutions that have created opportunities to sell or produce goods on a worldwide scale. The fastening technological development has led to a substantial shortening of the life cycle of most products, which implies that development costs have to be recovered in a short time period, before it becomes profitable for firms to introduce new products or processes. This requires immediate sales on world markets, where the magnitude of these sales is obviously influenced by the actions of international rivals. Facing this process of globalisation, firms develop complex strategies, depending on their technological potential.

In order to reduce the high and risky outlays for the development and sale of products on world markets, firms have the option to engage in cooperative agreements in the same industry, or with independent entities, such as research institutions or firms in other industries. The encouragement or tolerance by governments is a fact or subject of policy debate (e.g. Jacquemin and Soete (1994)). Such cooperation can take divergent forms, ranging from strategic cooperation or alliances without cross-participations, across joint ventures towards full cooperation and mergers. They can also encompass different functional activities, such as R&D, marketing, production of components, or information systems.

In the theoretical literature on R&D cooperation, not so much attention has been devoted to specific institutional and organizational aspects of R&D cooperation. "Non-cooperative conduct" of firms refers to a situation with competition (Nash) in R&D and in product market. "Cooperation" usually refers to cooperation in R&D and competition in the market. Full cooperation refers to cooperation in all considered dimensions, but will not be looked at here. One central theme hereby is how differences in conduct may affect efforts and innovative output.

One of the earliest analytical treatments of spillovers in oligopoly can be found in a paper by Ruff (1969)[1]. He analyzed a stylized growth model with Cournot firms deciding in traditional and modern sectors on labor inputs, while in the latter they can also increase the productivity by employing research workers. The firms recognize a potential "transmission" of knowledge from other firms, so that effective research effort per firm X_i equals

$$X_i = x_i + (n-1).\beta.x_j \quad (1)$$

with x_i own efforts (research personnel), n-1 number of rival firms, that all have x_j as effort and β a spillover parameter, $0 \leq \beta \leq 1$. Research efforts organized in a cooperative research laboratory with perfect transmission of knowledge and equal sharing of cost, while preserving Nash behavior in labor markets, result in a more progressive economy than with non-cooperative commitment equilibrium (open loop) in research efforts. He also found some support for the Schumpeterian hypothesis, contending that fewer firms with a resulting higher dynamic efficiency more than compensate static allocative inefficiencies.

In many ways recent work has been less ambitious than this historic preview. On the other hand many of the essential implications only were clarified recently. One central (and by now well known) result is that a critical spillover "drives" the comparison of non-cooperative and cooperative efforts. Some comments on the robustness and limitations of this inference are developed below.

3.1. Racing games

The game theoretic racing games developed in the eighties provided a more detailed analysis of the impact of conduct and spillovers on innovative efforts. Spillovers during the racing (Reinganum (1981)) and after the racing were looked at (Stewart (1983)).

In Reinganum's (1981) differential game analysis, rivals are competing for an invention that will give a higher (not lower) payoff to the winner of the stochastic race than to imitators. Each firm accumulates knowledge relevant to the innovation z_i, by investing in research and possibly by assimilating spillovers from rival's investments. The effective research effort at any time now equals the rate of knowledge accumulation, or in case of duopoly:

$$dz_i/dt = X_i(t) = x_i(t) + \beta\, x_j(t) \qquad (2)$$

The probability of successful innovation by a future date increases as the accumulated stock of knowledge at that time is greater in an exponential like fashion. The cost of research investments are $\frac{1}{2}x_i^2$ so that firms operate with diminishing returns.

The memoryless nature of the conditional success probabilities makes that commitment (open loop) and strategic (feedback) investments coincide, which highlights in some sense the special perhaps "static" character of the stochastic specification used. In a duopoly with winner takes all and symmetric equilibria, it can be proved that:

- with no spillovers in racing i.e., β=0, Nash rivals could be expected to innovate at an earlier date than cooperative firms, since they invest a higher rate at each instant in time than the cooperative rivals; but with perfect spillovers, i.e.β=1, one obtains the opposite tendencies. (3)

In many instances the innovator will (have to) share the market with imitators. Stewart (1983) was the first to analyse the impact of post-racing market sharing spillovers on constant efforts in a stochastic (exponential) racing model. The innovator gets σ of the present value of the innovation while each losing firm obtains $(1-\sigma)/(n-1)$. Winner takes all corresponds to no market-sharing spillovers or σ=1 and perfect spillovers result in a symmetric sharing of the innovative prize, or $\sigma=1/n$.

It seems like she was (one of) the first to explicitly note the role of a critical spillover level σ^* [2]:

$1/n < \sigma^* \leq 1$ (4)

so that σ^* represents an "intermediate" level of the market spillover. She showed that:

- for small spillovers non-cooperative symmetric efforts are larger than cooperative racing efforts ($\sigma>\sigma^*$); for large spillovers the opposite occurs ($\sigma<\sigma^*$); and there exist an intermediate level of spillovers for which the non-cooperative and cooperative efforts coincide ($\sigma=\sigma^*$) (5)

This finding is consistent with the earlier result (3) that applies to efforts changing through time, and only compares extreme values of the spillovers during the race. Stewart gave no explanation for the role of the critical spillover. But the impact of conduct on innovative efforts can easily be explained by the externalities that they impose on the rival's expected profits. One can indeed verify:

- A larger effort of a Nash rival results in a decrease in expected profit of a rival if spillovers are small ($\sigma>\sigma^*$). Cooperation that internalizes this negative externality results in a smaller racing effort. For large spillovers the opposite occurs, a positive externality is internalized through cooperation and a larger effort results ($\sigma<\sigma^*$). For the intermediate value of market spillovers there are no externalities and efforts coincide in cooperation and rivalry ($\sigma = \sigma^*$). (6)

The same interpretation also drives investment levels in two stage strategic settings (see below), as was first noted by De Bondt and Veugelers (1991).

Finally it may be noted that there are related "stochastic" models that abstract from timing, but have firms simultaneously committing to a choice of probability of success, with a higher probability implying higher costs (with diminishing returns) and abstracting from ex post rivalry and interactions (e.g. Stenbacka and Tombak (1995), Choi (1993)) They report among others, similar tendencies as reported in this section, including the role of a critical spillover.

3.2. Commitment games

Innovative investments also have been analyzed in more simple settings where in essence oligopoly firms decide simultaneously on a certain level of say product improvement (or on advertising) and on production or price levels .

An improvement of a personal computer may result in an improved competitive position, i.e. a market share effect at the expense of the rival. At the same time this may also attract new users in the market, i.e. a market expansion effect may occur, that may also benefit other firms. A clever advertising campaign for a brand may likewise result in an improved market share and may simultaneously draw the attention of reluctant consumers to these new products. Such a market expansion effect may benefit rivals as well, especially for goods and services in the beginning of the life cycle. Sometimes market expansion effects are small or absent.[3]

Spillovers that result from market expansion effects of advertising or quality improvements were analyzed in the beginning of the eighties. Nakao (1982) looks at the Nash commitments to R&D expenditures (open loop) in an oligopoly where firms only compete on quality, and where prices are set at a common cooperative level. The demand of any firm is dependent on the quality levels of all rivals and those are determined by their stock of technology. That stock increases because of own efforts and it depreciates because of patent termination or obsolence, possibly because of new rivalry. Within the model, technological spillovers occur only on the demand side. Friedman (1983) analyses in a subsequent paper similar effects with advertising spillovers working through linear demand and quadratic cost of efforts. More recent treatments looking at static settings with both demand and cost reducing spillovers and Nash commitments include Levin and Reiss (1988), and Cohen and Levinthal (1989).

Many results of these dynamic analyses pertain to the steady state and some details on underlying tendencies can be obtained by looking, as Nakao (1982) does too, at a market attraction specification that incorporates both market rivalry and market expansion effects. The quality enhancing efforts x_i of oligopolists determine firm demand q_i as follows:

$$q_i = f(p).A_i = f(p).(x_i^{\eta}/(\Sigma x_i^{\eta}).(\Sigma x_i)^{\alpha} \qquad (7)$$

Total market demand equals $\Sigma q_i = f(p).(\Sigma x_i)^{\alpha}$ with f(.) being a decreasing function of the common industry price p (Schmalensee (1976))[4]. The first factor of the attraction parameter A_i represents the impact of the R&D investments on market share (with symmetric efforts, $\eta.(1-1/n)$ is the elasticity of market share with respect to own investments). The second factor reflects market expansion effects (with symmetry, α is the elasticity of market demand with respect to total industry efforts). Efforts and price are chosen simultaneously and committed to.

It can be shown that with symmetric investments the impact of an investment on rival demand and on rival profits is driven by the magnitude of $(\alpha-\eta)$[5]:

- large spillovers are reflected in $(\alpha-\eta) > 0$, while small spillovers correspond to $(\alpha-\eta) < 0$; an intermediate critical level of spillovers is obtained for $\alpha=\eta$. (8)

For example, $\alpha=0$ means that investments provide no market expansion and only shift market shares. An increase in efforts by a firm then inflicts a negative externality on rival demand and profits. For a positive α and $\eta=0$ there are only market expansion effects and quality investments inflict a positive externality on rival demand and profits.

Kesteloot and De Bondt (1993) show that symmetric Nash efforts are smaller or larger than cooperative efforts depending on whether spillovers are small or large as defined above. They are again equal for the intermediate level with $\alpha=\eta$. In addition it is possible to look at the ratio of firm's investment expenditures to sales or the R&D intensity:

- With small spillovers the R&D intensity is smaller with Nash rivalry than with cooperation $(\alpha-\eta)<0$. For large spillovers $(\alpha-\eta)>0$ the opposite result occurs. For intermediate spillovers the intensities are equal with both conduct forms $(\alpha=\eta)$ (9)

Similar effects were detected by Motta (1992) in a vertical product differentiation model in which R&D expenditures with spillovers determine quality/price choices. For a demand structure in which total expenditure by consumers is fixed, there are no market expansion effects (like $\alpha=0$) and there is only a competitive effect. He finds that Nash rivalry will result in a higher effort than with cooperation, that would cut back on the negative competitive leakages. Other technology spillovers play no role in this. In case quality improvements also allow for market expansion, technological spillovers help to achieve this, and the usual type of critical spillover result ((6),(8)) obtains.[6]

3.3. Strategic investment games

The models above essentially ignore the strategic interactions between the innovative and the production side. Brander and Spencer (1984), Spence (1984) and Katz (1986) pioneered the analysis of multiple stage strategic investments and the analysis of spillovers. d'Aspremont and Jacquemin (1988) presented an influential strategic investment analysis in duopoly. Many subsequent models (e.g. Kamien, Müller and Zang (1992), De Bondt, Slaets and Cassiman (1992), Vonortas (1994), Beath, Katsoulacos and Ulph (1988)), built on this differ in details, but the common structure can be sketched as follows.

Firms compete in the product market in the second stage (à la Cournot or à la Bertrand) while in a first stage they compete on R&D investment, leading to cost reductions in the production process (or to enhanced demand). R&D may either be process or product oriented. Successful process R&D will result in production cost reductions: a given product can be fabricated more efficiently. Such process R&D can be formalized as a downward shift in unit production costs. Product R&D results in the introduction of new or improved products, which can be formalized as an outward shift of the demand curve.

The innovative rivalry is of a non-tournament kind. Thus there are many different research paths that firms can follow to improve their production process, so that whatever research path a firm follows, an equivalent amount of R&D spending will generate an equivalent reduction in production costs or enhancement in demand. Competitors cannot prevent other firms from getting equivalent improvements through spending equivalent amounts on R&D.

Firms' R&D efforts may be perfectly or imperfectly appropriable. In case of imperfect appropriability, part of a firm's R&D results leaks out to rival firms, resulting in cost reductions or product improvements for these rivals. These spillovers are formalized by a parameter β_i, with $0 \leq \beta_i \leq 1$. In most of the existing research spillovers are treated as identical between all firms although results on asymmetric spillovers are also beginning to appear (see below).

Cournot rivalry in the second stage has been most extensively studied. For zero spillovers non-cooperative strategic R&D results in higher efforts than with cooperation on R&D. Non-cooperative strategic R&D levels will typically (not always) decrease with the magnitude of the spillovers, while the cooperative investments tend to increase with increases in spillovers, see Figure 1.

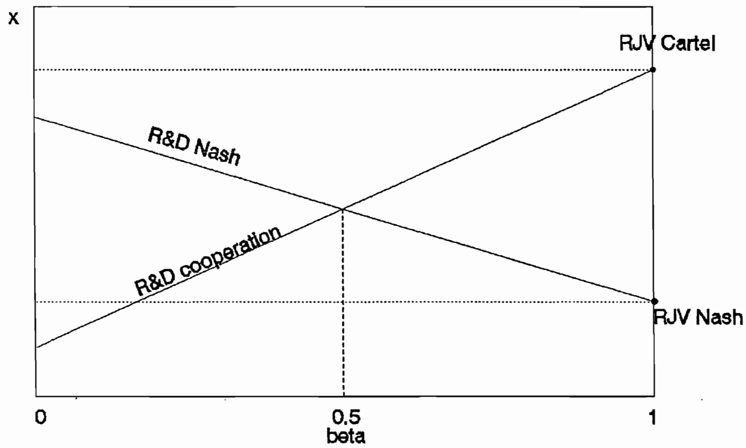

Figure 1: Strategic R&D investment x as a function of symmetric spillover β. (d=b=1)

There is a critical technological spillover level β^* for which they coincide and this spillover plays the same role as reported above for market sharing spillover. Mutatis mutandi, results (5) en (6) apply. In the case of duopoly with a linear demand $p_i=a-bq_i-dq_j$, $i\neq j$, $0\leq d\leq b$, $b>0$ the critical level is

$$\beta^* = d/2b \leq 1/2 \qquad (10)$$

With homogeneous goods d=b and $\beta^*=1/2$, and in a differentiated duopoly d<b and $\beta^*<1/2$.

When comparing non-cooperative and cooperative R&D levels, it is also interesting to look at different spillover levels for groups that are cooperating and those that are competing (Katz (1986), De Bondt, Sleuwaegen and Veugelers (1988), Beath a.o. (1988), Kamien a.o. (1992)). It would not be surprising if voluntary spillovers (with cooperation) were larger than involuntary ones. In Figure 1 it can be seen that cooperation with perfect spillovers ("research joint venture cartel") results in the highest effort (and cost reduction) (Kamien a.o. (1992)[7]).

3.4. Model specific variations

In reality firms can decide simultaneously or sequentially on investment and output levels and this is of importance for characterizing the strategies. In the racing and quality commitment models referred to above, this does not matter. But in the other settings it does. De Bondt and Veugelers (1991) show that strategic behavior, resulting from sequential rather than simultaneous Nash strategies in duopoly à la d'Aspremont-Jacquemin, leads to more R&D than necessary to minimize costs, depending on whether the spillover level is larger than the critical spillover level β^*. This coincides with the level that drives the comparison with cooperative efforts, but it is unclear whether this will hold with general demand and spillover specifications (Leahy and Neary (1995)).

Theoretical discussions sometimes state the comparison between non-cooperative and cooperative efforts in terms of slope of reaction functions. In strategic investment models with quadratic payoffs the best response of a firm's R&D to another rival's efforts is upward sloping when spillovers are larger than the critical level (β^*) and in that case the investments are strategic complements (Bulow, Geneakoplos and Klemperer (1985)). For lower spillovers they are downward sloping and efforts are strategic substitutes. Using the elementary analysis (downward sloping reaction curves in output and upward sloping reaction curves in prices) it is then explained that for small spillovers (downward sloping), cooperation will result in smaller efforts and with large spillovers (upward sloping) in larger efforts.

But this line of reasoning clearly is **not** robust across various models. In a duopoly racing model with small market spillovers, the best response of one rival vis à vis the other is upward sloping. Small spillovers ($\sigma>\sigma^*$) preserve the winner takes all character of the game and rivals increase race efforts as a response to increases by others. Cooperation will temper these racing efforts. The opposite occurs with large market sharing spillovers ($\sigma<\sigma^*$). Likewise in the market share quality specification and say duopoly, reaction curves will be negatively sloped both for large and small spillovers [8]. All of this would seem to tell that it is unlikely that the search for slopes of R&D reaction curves will tell anything about the likely impact of cooperation ! One thing that does stand is that critical spillovers appear to guide the magnitude of the efforts in both scenarios of conduct.

Finally a few words on the determinants of the critical spillover level. It seems clear that in more general settings this level will depend on the curvature of the demand function. For example, Simpson and Vonortas (1994) find that a research consortium operates a single research facility and disseminates all results to members, who may or may not be able to use all the information. This strategic investment setting is slightly different from the one discussed above, and they detect incentives toward higher cooperative effort with a strictly concave demand, regardless of spillovers. With linear or convex demand the more usual prediction (6) applies.

The importance of demand is confirmed by the inference from the d'Aspremont-Jacquemin type of models that the critical β^* moves closer to zero as products become more differentiated, see (10). This means that cooperative R&D can be expected to exceed the non-cooperative level for a much wider range of, also smaller, spillover values. The negative competitive effects of externalities are less likely to apply if each rival operates in a more segmented market. Likewise in a less competitive industry (because of fewer rivals), cooperative racing (as in (Stewart (1983)) will result in enhanced racing efforts for a wider range of sufficiently large spillovers [9].

In reality firms may undertake different kinds of R&D activities, for example generic (or more basic) research with possible spillovers β and afterwards development (more idiosyncratic) efforts with no spillovers. Vonortas (1994) shows that this complicates the comparison of non-cooperative and cooperative efforts. For small spillovers $\beta \leq \beta^*$ cooperation reduces generic and development efforts, but the critical level β^* for which the opposite applies now exceeds 1/2, be it only slightly when the technological opportunities of development are weak and the (linear) demand curve is flat. [10]

Finally it may be that not all firms are part of the cooperative agreement. For example, one group of cooperating firms competes against other rivals in an industry with symmetric spillovers β. In a variant of the cost-reducing game discussed above, De Bondt and Wu (1995) show that such cooperation will also result in higher R&D investments for the cartel than for the competitive fringe, for oligopolies with large spillovers (β>1/2). But this enhanced effort will also occur in industries in which industry wide symmetric spillovers β are small, provided only that cooperation results in a sufficient amount of additional information sharing ε. More precisely for:

$$\varepsilon \geq (1-2.\beta)/(n-k+1) \qquad \beta<1/2 \qquad (11)$$

with k cooperating firms that realize spillovers $\varepsilon+\beta$, in an n-firm industry. Poyago-Theotoky (1995) confirms this inference for perfect information sharing ($\varepsilon=1-\beta$).

4. Spillovers, innovative efforts and implications

As Schumpeter (1943) emphasized, free entry and perfect competition is incompatible with innovation, so market imperfections and a few firms may be conductive to innovation. But at the same time the threat of new competition serves as a powerful spur to innovative efforts and hence market protection cannot be too strong either. This raises the question as to what form of market structure is most conductive to processes of creative destruction. Empirical and theoretical research tended to support the view that some form of intermediate rivalry, with some barriers to imitation but typically not too much, appears as most appropriate. The early game theoretic approaches tended to dismiss these theoretical insights because they were based on decision theoretic analysis, i.e. partial equilibrium. At the same time racing settings typically posited perfect patent protection and thus did not analyze the impact of possible spillovers (but see above).

This is important because spillovers a priori have conflicting effects on innovative efforts. This potential role is thus reminiscent of the Schumpeterian conflicting effect of "competition". Spillovers typically temper research efforts, since they tend to limit the appropriability of individual activities. On the other hand, spillovers may stimulate technological change since information transfers may allow synergies to be realized, duplication to be eliminated and innovation costs to be reduced. This raises the question as to their net effect and to the relevance of this for firms and society. What does recent analysis has to say about this ?

4.1. Spillovers and individual R&D

Symmetric intra-industry spillovers limit the appropriability of a firm's R&D investment, but at the same time they allow it to learn from others. The net effect is either to discourage or to stimulate .

4.1.1. Disincentive effect

The typical inference is that spillovers limit the efficiency of the R&D investment to create a competitive advantage and thus (Spence (1984) and many others):

- positive and symmetric intra-industry spillovers tend to reduce the incentive for non-cooperative investments in R&D. (12)

An increase in the number of oligopolists in a cost-reducing non-cooperative game likewise typically tends to reduce efforts (De Bondt a.o. (1992)).

Market-sharing spillovers in racing provide similar disincentives. Delbono and Denicolo (1990) studied a stochastic race at the end of which a technological improvement lowers cost of the winner, while losers continue with the old technology. "Market sharing" may occur even though knowledge does not spill over to rivals. Racing firms then collect a profit from using an old technology, as long as racing continues[11]. They show that:

- constant racing efforts are stimulated by the difference in profits between winning and losing, i.e. by the "competitive threat" (Beath, a.o. (1988)) (a),
- and by the difference between the winner's profits and existing profits ("profit incentive" = incentive to invest if there is no rivalry) (b) (13)

The first prediction (a) is consistent with the results in Reinganum (1982), namely that a lower reward for the innovator or a higher one for the imitator reduces the Nash research efforts of any of the racing rivals. They also show that Cournot rivalry entails reduced racing efforts, since with post-innovation Cournot "sharing", the loser is better off than with Bertrand competition. Also Stewart (1983) predicts that non-cooperative efforts will be discouraged by increasing market spillovers that are already small[12]. Clearly all of this is in the spirit of the disincentive prediction (12).

4.1.2. Incentive effect

But casual empiricism and econometric work also suggest that spillovers may fail to discourage, but instead may stimulate individual efforts. This "reversed" prediction has emerged in the context of a number of the earlier models that look at commitment, instead of strategic choices. The intuitive reason is that strategic investment efforts have a competitive and a market effect: The competitive effect of cost reduction or demand enhancement is countered by Nash rivals and its effectiveness diminishes as spillovers increase, hence spillovers result in a "competitive leakage". The market effect is that because of the spillovers, all industry members operate with lower cost or higher demand, thus larger output, and this should stimulate efforts, hence spillovers provide a "market expansion effect".

In strategic investment models the competitive leakage effect tends to dominate and more spillovers typically lower effort, unless other factors such as a not too competitive oligopoly (high degree of product differentiation, small number of rivals) render the leakage effect small and then the opposite tendency may apply.

In commitment settings where firms choose simultaneously on R&D and say output, the first competitive leakage is (more) absent, the market expansion effect dominates and larger spillovers enhance non-cooperative efforts (e.g. Friedman (1983), De Bondt and Veugelers (1991)). In a quality enhancing commitment game, for example, a firm's non-cooperative (and cooperative) efforts increase as the market expansion effect α becomes more important (Kesteloot and De Bondt(1993)).

This also explains why many of these papers (including Reinganum (1981), Motta (1992), Vonortas (1994)) find that:

- cooperative R&D investments are typically stimulated by larger spillovers (14)

see Figure 1.[13] It is also consistent with the finding of Steurs (1995) that inter-industry spillovers stimulate R&D investments, since they have no competitive effects for rivals that operate in different industries.

It is difficult to say whether commitment rather than strategic investment is the better description of reality. But the former clearly can not be excluded, since among others adjustment costs tend to be very high, while information to calculate or to behave as if calculating the subgame perfect strategies may not be present at the time of decision making. [14]

In the strategic investment duopoly analyzed by De Bondt and Henriques (1995) it also turns out that asymmetries in spillovers may change the disincentive effect, even when homogeneous products provide little room for a limitation of competitive leakage. If one firm is better at learning (receives more spillovers) than the rival, it may well be stimulated by an increase of not too large spillovers.

Cohen and Levinthal (1989) likewise argue that learning costs are substantial in the long run. R&D investments not only lead to innovations, but also increase the capacity of firms to absorb know how. This determines the extent to which firms are actually able to use the spillovers and hence the matter may also stimulate innovative activities.

Levin and Reiss (1988) distinguish the extent of spillovers and the productivity of the spillovers. These two form the total spillover effect. If the spillover productivity increases, the total spillover increases, but this will not, as the proposition states, decrease R&D investment. Instead R&D investment will be increased because own R&D is enhanced by increases in industry knowledge.

The commitment nature of R&D flow expenditures in racing games also results in an increase in efforts as the number of racing contenders increase[15]. The plan is to stop these outlays as soon as the innovation appears: both expected revenue and expected costs are reduced by more rivals and the effect is to stimulate individual efforts (Lee and Wilde (1980), Reinganum (1984)). Delbono and Denicolo (1991) combine such a race by Cournot rivals to obtain drastic or non-drastic improvements in profitability. Drastic innovations effectively eliminate all rivals and give the winner a monopoly power. Equilibrium efforts to obtain such a price are stimulated by the number of rivals. But this prediction does not appear for non-drastic improvements that say lower only moderately the costs of the winner; with linear demand and a specific hazard rate function specification, individual efforts may be stimulated by more rivals in cases with sufficiently likely discovery (or high discount rate)[16].

4.2. Spillovers and knowledge level

It should be clear that symmetric spillovers allow a more efficient use of scarce R&D resources. In the analyzed context it can be expected that the total amount of cost reduction, per dollar spent on R&D, increases as the spillover augments. Larger spillovers in other words enhance a higher innovative productivity, since among others they allow duplication to be eliminated.

But of course the firm nor society is interested in productivity per se. And it turns out that in a number of symmetric settings it is not this productivity but rather the knowledge level created in each firm, that is driving the individual and general performance.

The individual knowledge level or effective R&D that results from innovative activities in an industry equals in a cost-reducing game the actual reduction in the unit cost of production. With symmetric spillovers and investments, and with n firms it is $X=x+x.(n-1).\beta$ and the essence of this concept can already be found in pioneering contributions. So with perfect appropriability ($\beta=0$), R&D investment and effective R&D coincide. But with the existence of spillovers, the effective R&D of the individual firm is determined by its R&D investment increased with the part of the investment of other firms in the industry that spills over to that firm.

In the generalized d'Aspremont-Jacquemin model analyzed by De Bondt a.o.(1992), with strategic cost-reducing R&D in an n-firm duopoly the critical spillover β^* level has an analogous effect for the comparison between non-cooperative and cooperative effective R&D:

- For small spillovers ($\beta<\beta^*$) the effective R&D with cooperation is smaller than with non-cooperative efforts. For large spillovers $\beta>\beta^*$ the opposite applies, while equality obtains for $\beta=\beta^*$. (15)

This result is of course driven by the comparison of the R&D efforts. In case conduct also changes the spillovers, a similar picture emerges as in Figure 1.

For example, when cooperation results in perfect spillovers, effective R&D is larger than with Nash efforts without spillovers. This result has been confirmed in a differential game setting (Reinganum (1981) provided firms are sufficiently near the given time horizon. In the beginning of the race, howerver, the cooperative rate of knowledge accumulation with perfect spillovers is typically lower than would be the case with Nash and no spillovers.

A systematic analysis of the impact of spillovers on effective R&D is quite involved but De Bondt, a.o. (1992) argue [17]:

- Effective non-cooperative strategic R&D will be maximized for an intermediate spillover β^e with $1/2 \leq \beta^e \leq 1$ ($\beta^* = \beta^e = 1/2$ in the homogeneous goods case and $1/2 < \beta^e \leq 1$ for differentiated products), see Figure 2. (16)

The intuition for this result is simple. Individual strategic R&D is typically discouraged in an increasing way through the existence of spillovers. With a large number of firms, an increasing portion of R&D efforts of competitors compensates for the reduction in own R&D investment. Of course investments of competitors individually also decrease. The resulting effect is that first effective R&D increases and then, when a critical spillover is reached, it starts to fall.

It can be shown that in differentiated oligopolies the critical spillover β^e for which effective R&D is maximized tends to increase as the structure of the industry becomes less competitive (more product differentiation and a smaller number of rivals). In a duopoly with high product differentiation, effective R&D would be higher with perfect than without spillovers. This is consistent with Reinganum's (1981) result that perfect spillovers in a winner takes all differential game may also result in an earlier non-cooperative introduction, than if knowledge were pure private among competing rivals.

Steurs (1995) has shown in a related setting that the critical spillover level β^e tends to decrease as the inter-industry spillovers ϕ increase. As an example of the latter, one may consider better and cheaper ways to produce plastic elements

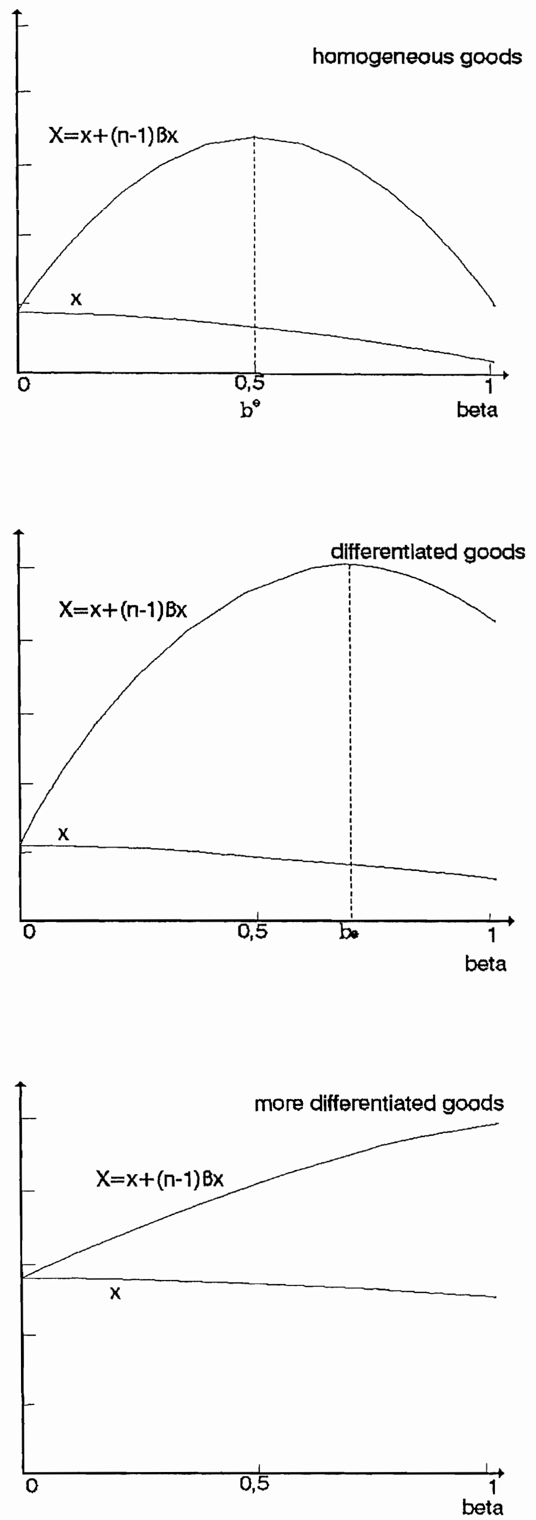

Figure 2 : Strategic investment x and effective R&D X as a fuction of spillover level.

developed in the petrochemical industry, that could to some extent be used in the computer industry to design components and assembly of products, that allow cheaper production. Symmetric inter-industry spillovers tend to enhance the disincentive effect of intra-industry spillovers, since they tend to increase the competitive leakage effects. In fact effective R&D may decrease with intra-spillovers β, if inter-industry communication ϕ is sufficiently large [$\phi>(1-(1/n)$], which becomes more unlikely as more rivals compete in strategic investments.

The result is of significance since in the same setting the firm output, consumer surplus and firm profits gross of R&D expenditures are also maximized at β^e. Typically, some but not too much appropriability appears to be the most conductive for innovative output. A similar prediction emerged from decision theoretic analysis, in which some but not too high barriers to imitation, limiting entry or preemption, were found to be most conductive to innovative activity in a wide class of circumstances (Kamien and Schwartz (1976), De Bondt (1977)).

4.3. Spillovers, profits and static welfare

Stewart (1983) found in a technology race model that expected profits are maximized at the critical market sharing value σ^*. In non-cooperative oligopolies, with products not too differentiated and rivals sufficiently numerous, individual profits and also static welfare will first increase and then decrease with the level of symmetric spillovers [18]. In less competitive structures spillovers tend to stimulate both profits and welfare. This result is driven by the effect of spillovers on the created knowledge level (effective R&D).

In addition it is typically so that industry wide cooperation improves on profitability and on static welfare too, if spillovers are large enough[19]. The full implications cannot be drawn without an additional stage that endogenizes the spillovers (see e.g. Katz (1986)). With homogeneous settings and spillovers equal to the critical level of 1/2, firms would maximize individual profits and could not improve on this, at that spillover, by cooperating (in view of (6) investments and profits are the same at the critical β^*). They could improve on profits only if the cooperation succeeds in improving spillovers and then static welfare would also increase[20] . Steurs (1995) found that inter-industry cooperation is likely to improve more on welfare and on profits if inter-industry spillovers ϕ are sufficiently high compared to inter-industry communication β ($\phi>2\beta-1$). Also in this case the private incentives work in the direction that improves on static welfare.

5. Asymmetric spillovers

Most of the above refers to symmetric oligopoly settings and equilibria. Even in symmetric structures there may be asymmetric equilibria and in a number of reported models those cannot be excluded for some of the parameter values [21]. Since oligopolies in reality seldom are symmetric, for historic, stochastic reasons and strategic choice, it is of interest to look at some of the implications.

5.1. Research cartels

A first complication is that not all firms may be part of the cooperative venture, while cooperation in itself allows to improve on information sharing. Poyago-Theotoky (1995) and De Bondt and Wu (1995) among others, analyze an extension of the strategic investment game in which k firms coordinate R&D investments and play Nash in R&D against the n-k remaining rivals. All firms play Cournot in the second stage. Cooperating firms may possibly increase spillovers by $0\leq\varepsilon\leq1-\beta$ for all participating members. The stability of the coalition size k (in stable configurations no firm wants to join nor leave (d'Aspremont, Jacquemin, Gabszewicz and Weymark (1983)) is very sensitive to the possibility of such an increase. In case this is not possible, stable cartel sizes tend to be small. Even though individual profits may increase for members of the coalition as the size grows, it is in many cases better not to join it or to leave it. It may be better to free ride on the cartel's large cooperative investments in industries with large spillovers or to take advantage of its low R&D efforts and output in situations with low spillovers (à la Salant, Switzer and Reynolds (1983)). But with better information sharing, large and industry wide coalition sizes tend to become stable for wide ranges of parameters.

Consistent with this, Kesteloot and Veugelers (1995) find that better information sharing in a symmetric duopoly, reduces the incentive of firms to cheat on the agreed upon strategic investments, in essence because upon detection they tend to lose the benefits of this additional sharing by going back to rivalry. The cheating incentives tend to be particularly high, in ventures with otherwise high spillovers such as with generic research (and low with low spillovers as with development R&D).

Simulations results of the R&D cartel setting also suggest:

- In a wide class of circumstances (with not too small industry spillovers and additional information sharing in the cartel), consumer surplus (and static welfare) tend to increase with the size of the R&D cartel in oligopolies with a small number of firms. Otherwise they first increase and then decrease as membership becomes more numerous, see Figure 3. (17)

There is, however, a conflict between the size that maximizes firm profits and the one that maximizes consumer surplus and static welfare, but the exact inference appears parameter specific.[22]

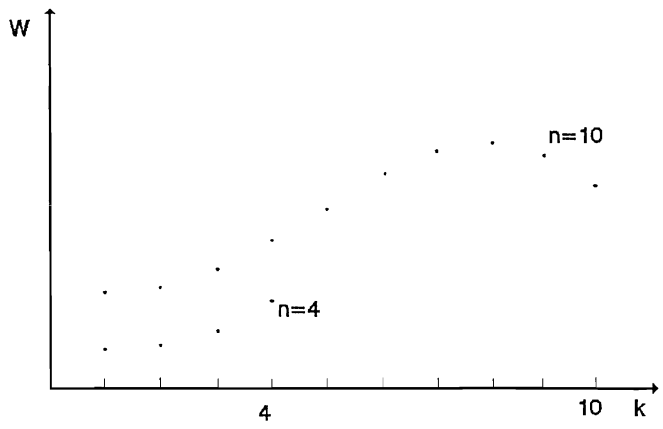

Figure 3 : Static welfare (W) as a function of the size k of an R&D cartel in a n firm industry. (β = 0.6, ε= 0.3)

Similar tendencies apply for the level of the industry wide spillover,

These findings are consistent with the Kamien and Zang (1993) results of equally sized R&D cartels that perfectly share information among its members (ε=1-β). They show that splitting a single R&D cartel into several symmetric competing ones would yield lower prices. And a split in half would be best for knowledge creation and low prices. But this would also reduce firm profits and the impact of the split in half on static welfare can go either way. Combs (1993) considers a model in which the probability of success in innovation depends on the sharing of information. She argues, however, that stable coalition sizes can never exceed the size that maximizes total surplus.

The above results suggest again that in many cases innovative activities are highest in industries with an intermediate degree of rivalry (coalition size, or industry spillovers not too large). In more exceptional circumstances an industry wide (grand) cartel may be most conductive to technological change (see also above).

5.2. Role playing

One of the central themes in I.O. and business strategy concerns the question whether it is better for a firm to innovate or to wait and imitate. Incumbent firms often appear to be "slow" to introduce major innovations, that in many cases seem to be coming from new entrants (Jewkes, Sawyers and Stillerman (1958)). Only recently, for example, Bower and Christensen (1995) claimed: "One of the most consisting patterns in business is the failure of leading companies to stay at the top of their industries when technologies and market change".

One well known reason for this tendency is the incumbent's fear of cannibalization or the "never change a winning team" disincentive. Reinganum (1983) looked at a stochastic cost reducing innovation that is drastic (winner takes the whole market). The existence of a challenger firm leads an incumbent firm to invest more than it otherwise would. But in Nash equilibrium it invests less than the challenger, essentially because it has an incentive not to terminate the (stochastic) profit flow from existing products. Challengers invest more and are more likely to win the patent race. While she obtains similar tendencies with non-drastic innovations, i.e. with some market sharing, the result is less clear cut (obtains for a more narrow set of parameter values). One problem with the cannibalization explanation is of course that if leadership were essential for incumbents, one would observe them figuring out a way to counter this, say by placing responsibility for building a disruptive technology business in an independent organization.

In a later paper Reinganum (1985) looked at sequential moves in development activities with technological uncertainty, but without spillovers. First movers have an incentive to reduce efforts to force rival to do the same. As a result first-movers are less likely to win a race and would, instead, prefer to be followers. Baik and Shogren (1992) analyzed the strategic efforts that affect the likelihood of winning a contest. The underdog moves first and underinvests (relative to the simultaneous move efforts) in order to reduce the wrath of the favorite who moves second. And a final interesting contribution is provided by Rosen (1991) who argues that innovative strategies cannot be separated from then pre-innovative technology of the incumbent or entrant. Duopolists commit simultaneously to either a safe or more risky project and to the scale at which they intend to pursue the chosen project. For competence-enhancing discontinuities or improvement innovations (see section two), a low-cost firm invests more and in safer projects than the high-cost duopolist. Symmetric spillovers are argued to lead firms to preferring safer projects[23]. The low-cost rival also invests more in add-on projects and less in revolutionary (drastic) innovations. This is consistent with an equilibrium analyzed by Rosenkranz (1995) in which a high quality and high profit firm enters earlier than the low quality rival (given that willingness to pay for high quality is sufficiently high)[24].

De Bondt and Henriques (1995) compare sequential with simultaneous strategic investments in a cost-reducing game with asymmetric spillovers. They find that, see Figure 4:

- both rivals benefit from a leader announcing its investment first, in case that the spillovers that the leader absorbs β_L are large (>d/2b) and the spillovers the follower receives β_F are small (<d/2b) (a)
- the leader invests less and the follower invest more than with a simultaneous announcement and this will typically cause prices to increase (b) (18)

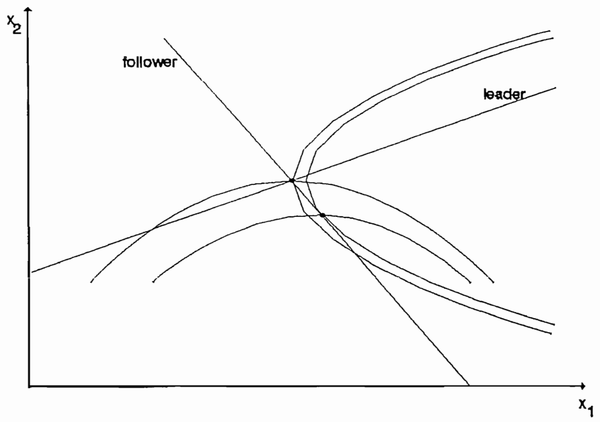

Figure 4: Reaction and iso-profit curves with asymmetric spillovers. Leader invests x_1, and receives perfect spillover, and follower invests x_2 and receives zero spillover.

Simulations indicate that in such a sequential equilibrium the efforts of the leader will increase in case his initial cost level is reduced compared to that of the follower.

The driving force of result (8) however, is the asymmetry in the spillovers and the fact that the leader will be able to "learn" more. One can think of writing a paper that does not milk the issue and hence followers will build on it. This will result in more citations to the innovating paper and also the leader is better off. Scholars that are likely to be cited more, say because of reputation, will as a consequence lead and this is better for everyone than if one attempted to compete head on.

In industries one likewise often observes innovative entrance on a smaller scale with aggressive massive imitation. The follower gives way: it is better than trying to get through the door together (Schnaars (1994)). The leader knows it may benefit from the late massive entry of the follower, that will help say to open up the market. And as a consequence it invests less and the follower invests more than he would do otherwise. If the leader is more efficient this may still mean its efforts are bigger than those of the follower, consistent with Rosen (1991).

6. Urgent issues

It is clear that many more issues await treatment. More work is needed on asymmetries, e.g. exploring the impact of spillovers in vertical market organizations. In reality spillovers are to a certain extent endogenous and this is possibly interacting with exogenous information leakage. De Fraja (1993) modifies (in essence) the Stewart (1983) racing model to include technological disclosures (endogenous spillovers) in racing efforts. He shows that symmetric Nash commitments to full disclosure are likely when market sharing spillovers are high. When such sharing is low, no disclosure obtains. And asymmetric disclosures are also possible, when the underdog firm that receives the smallest piece of the innovative pie does not disclose and the other does. In other words, the underdog only "receives" information. This is in line with the role playing tendencies discussed above, and awaits further investigation.

The information that can be supplied to cooperative partners is private and the know how each firm discloses is non-verifiable, so that spillovers cannot be contracted on. This asymmetric information may prevent research joint ventures from starting (Pérez-Castrillo and Sandonis (1994)). Agency problems also root in the asymmetric objectives and information between "researchers" and owners of the firm or government trying to stimulate innovation (e.g. Veugelers and Kesteloot (1994), Cassiman (1994), Vergauwen (1995)). Firm (and technology policy) organizations are a response to these problems: and "competing on science and technology means competing on the organization of information (Clark (1989))."

There is of course a need for empirical testing. Existing work tends to look at the broad spillover definition (also embodied) and next to methodological problems a lack of adequate data is striking. Despite these problems, the most robust finding is that

R&D spillovers are present and their magnitude may be quite large. The disincentive effect is only weakly supported by the data, but this is no surprise for theory (see above). More work will need to be done to understand the mechanisms of knowledge transfer. To this end, an attempt must be made to model the channels through which spillovers occur. More work is also needed to understand the strategic interaction of firms doing R&D in similar areas, with or without spillovers.

7. Conclusion

The search for exciting theoretical I.O. will come from a combination of factors. First, there is a need for patience, in the sense that robustness is looked for and that a relation with earlier findings is explored. In this paper an attempt was made to search for general tendencies among specific models that look at spillovers in innovative activities. A number of inferences appeared in a wide class of settings, including stochastic racing models, (static) stochastic models, dynamic and static commitment models, and strategic investment models. They all, for example, "agree" on :

- tendencies summarized by Figure 1 and the role of a critical spillover level that drives the comparison between symmetric cooperative and non-cooperative efforts since it is crucial for the sign of the externalities that investments inflicted on rivals;
- the disincentive effect of symmetric spillovers for strategic investments and the positive effect of such spillovers for investment commitments and cooperative efforts;

Likewise it appears that innovative output in many cases is highest when appropriation is neither perfect nor free, although circumstances also emerge where any lack of appropriation will discourage innovative efforts. These tendencies also appeared in a wide variety of settings, with lack of appropration coming from low entry and imitation barriers or from a high number of competing rivals.

Second there is the need for more inspiration from the demand side. A high proportion of supply induced literature is inevitable and needed, some of the best work simply comes from trying to understand and trying to get things right. But at the same time it would be nice to see more demand induced work. In many cases the gap is still very wide and this is not a new phenomenon.

Still it seems like at the European level we are working towards a more developed scientific community, and the view on where we are going is important. Some fear that the European science scene in economics will move towards more rigor and more papers (and citations) but to less relevance, policy influence and support of excellent undergraduate and graduate education (along these lines, see e.g. Frey and Eichenberger (1993)). It is a point well taken in general and for the field of I.O. in particular. But we must be optimistic; once we recognize the challenge and agree on it, we can define the problem and then solutions in many instances tend to suggest themselves. Rewarding inventions and innovation in the profession, universities and research institutions will be possible, if we succeed in stimulating and internalizing spillovers on the supply side (among scientists) and on the bridge between the demand side and science.

30/8/95

[1]In the first volume of the "Journal of Economic Theory" !.

[2]After some substitutions, see also Reinganum (1989), one obtains $\sigma^* = 1/n + [1- (1/n)] / P.h'$, with $h'>0$ the derivative of the hazard function evaluated at the corresponding symmetric equilibrium and P the value of the innovation at the time of its introduction.

[3] According to Roberts and Samuelson (1988), advertising on low tar cigarette brands appears to have positive market spillovers, while advertising on regular cigarettes tend to have only market share effects.

[4] When f(p) is replaced by a function that is multiplicative separable in prices, the commitment and strategic equilibria coincide (there is no room for strategic use of R&D) (Lee(1986)) and adding price equilibria would not change the inferences.

[5] It can be shown that with equal choices of R&D investments $\text{sign}(\delta.\ln q_j/\delta.\ln x_i) = \text{sign}\ \delta V_j/\delta x_i = \text{sign}\ (\alpha-\eta)$ with $j\neq i$, q_i and q_j output, profits $V_j=(p-c).q_j-r.x_j$, c a constant unit of cost of production and r a per unit cost for an R&D input x_j.

[6]Motta also considers an additional stage of entry and shows that cooperation may also allow more firms to enter.

[7]Amir (1994) points to differences between the d'Aspremont-Jacquemin (1988) and Kamien a.o (1992) modelling of spillovers.

[8]With more firms they will be negatively sloped for small spillovers and may be positively sloped for large spillovers if there are many rivals.

[9] Since it can be shown that $\delta\sigma^*/\delta n<0$ with σ * defined in footnote 3.

[10] For $\beta>1/2$, $\beta^*=3\Gamma b/(6\Gamma b-1)$ with Γ a parameter reflecting the cost of development efforts and b the slope of the linear demand curve in a cost-reducing game with Cournot competition.

[11] This sharing assumes no spillovers. One could extend their analysis to include spillovers in cost reduction. This should give insights comparable to the findings on σ.

[12] Note that a larger value σ implies a smaller spillover. Stewart shows that non-cooperative investments increase with σ for $\sigma\geq\sigma^*$.

[13] Some simulations seem to indicate that the complication looked at by Vonortas (1994) does not change the inferences made here. In Choi (1993) however cooperative investments appear to be discouraged by higher spillovers.

[14] With strategic investments and no spillovers, firms tend to have lower profits than with commitment (open loop) (Brander and Spencer (1983)). But spillovers render this comparison ambiguous in general.

[15] In race settings with technological uncertainty and winner takes all, more rivals also discourage sunk innovative investments that increase the probability of a breakthrough in a small time interval, given that it did not occur earlier (Loury (1979)). The reason is that more rivals reduce the expected revenue from investments while the sunk cost remains the same, so that a disincentive of rivalry appears.

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[16] This setting however, assumes that current Cournot profits are sufficient to self-finance drastic or non-drastic innovations, regardless of the number of firms in the industry. Especially drastic improvements may, however, incite large innovative efforts and may consequently create a binding self-financing constraint.

[17]They also show that non-cooperative effective R&D typically decreases as the number of rivals increases, since individual efforts are also discouraged by more rivals.

[18]In a homogeneous oligopoly the maximum is also achieved for the critical spillover $\beta^*=1/2$. For differentiated oligopolies things are a little bit more complicated, see De Bondt a.o. (1992).

[19] One reported exception is the case of large inter-industry spillovers ϕ that accompany low intra-industry spillovers β (Steurs (1995)).

[20]The cooperative strategic R&D levels are still socially insufficient (Suzumura (1992)). The first best x^{fb} is obtained by having a planner maximizing static welfare. It can be shown that for large β, $x^n < x^c < x^{fb}$; for small β, $x^c < x^{fb} < x^n$ with c cooperation and n Nash. It may also be of interest to compare actual welfare with first best welfare (W^{fb}), by dividing the one through the other (W/W^{fb}). It appears that welfare performance (W/W^{fb}) of the non-cooperative oligopoly, would first increase but quickly decrease with increasing spillovers, or with a low number of firms in the industry it would always decrease with spillovers increasing.

[21] Sufficiently strong diminishing returns tends to eliminate this (and stability problems) in d'Aspremont-Jacquemin type of models.

[22] In the asymmetric setting of De Bondt and Wu (1995) with perfect information sharing in the cartel, member profits will first increase and then decrease with k. Member firms thus have an incentive to restrict the size of the coalition, possibly below the one that maximizes consumer surplus and static welfare. The exact inference is highly dependent on the information sharing properties.

[23]With cooperation spillovers could result in multiproject scope economies (Van Cayseele (1987)).

[24]Drastic innovations give monopoly (or duopoly in case of a tie).

REFERENCES

Amir, R., 1994, Strategic R&D with Spillovers: Comments on the Literature, Universität Mannheim, working paper.

Arrow, K.J., 1962, Economic Welfare and the Allocation of the Resources for Invention in Nelson, R.R. (Ed.), **The Rate and Direction of Inventive Activity**, Princeton University Press, Princeton, 609-627.

Baik, K.H. and Shogren, J.F., 1992, Strategic Behavior in Contests: Comment, **The American Economic Review** 82, 359-362.

Baumol, W.J., 1993, **Entrepeneurship, Management, and the Structure of Payoffs**, The MIT Press, Cambridge

Beath, J., Katsoulacos, Y. and Ulph, D., 1988, R&D Rivalry vs. R&D Cooperation under Uncertainty, **Recherches Economiques de Louvain** 54, 373-384.

Bernstein, J.I., 1988, Cost of Production, Intra- and Interindusty R&D Spillovers: Canadian Evidence, **Canadian Journal of Economics** 2, 324-347.

Bower, J.L. and Christensen, C.M., 1995, Disruptive Technologies: Catching the Wave, **Harvard Business Review** , 43-53.

Brander, J.A. and Spencer, B.J., 1984, Strategic commitment with R&D: the Symmetric Case, **Bell Journal of Economics** 14, 225-235.

Bulow, J., Geanakoplos, J. and Klemperer P., 1985, Multimarket Oligopoly, Strategic Substitutes and Complements, **Journal of Political Economy** 93, 448-511.

Cassiman, B., 1994, Research Joint Ventures and Optimal R&D policy with Asymmetric Information, J.L. Kellogg Graduate School of Management, CMSEMS Discussion paper 1105, Northwestern University.

Choi, J.P., 1993, Cooperative R&D with product market competition, **Internatianal Journal of Industrial Organization** 11, 553-571.

Clark, K.B., 1989, What Strategy Can Do for Technology**, Harvard Business Review** Nov-Dec, 94-98.

Cohen, W.M. and Levinthal, D.A., 1989, Innovation and Learning: The Two Faces of R&D, **The Economic Journal** 99, 569-596.

Combs, K.L., 1993, The Role of Information Sharing in Cooperative Research and Development, **International Journal of Industrial Organization** 11, 535-551.

d'Aspremont, C., Jacquemin A., Gabszewicz, J., and J. Weymark, 1983, On the Stability of Collusive Price Leadership, **Canadian Journal of Economics** 16, 17-25.

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

De Bondt, R., 1977, Innovative Activity and Barriers to Entry, **European Economic Review** 10, 95-109.

De Bondt, R., Sleuwaegen, L. and Veugelers, R., 1988, Innovative Strategic Groups in Multinational Industries, **European Economic Review** 32, 905-925.

De Bondt, R. and Veugelers, R., 1991, Strategic Investment with Spillovers, **European Journal of Political Economy** 7, 345-366.

De Bondt, R., Slaets, P. and Cassiman, B. 1992, Spillovers and the Number of Rivals for Maximum Effective R&D, **International Journal of Industrial Organization** 10, 35-54.

De Bondt, R. and Henriques, I., 1995, Strategic Investment with Asymmetric Spillovers, **Canadian Journal of Economics** 28, 656-674.

De Bondt, R. and Wu, Ch., 1995, Research Joint Venture Cartels and Welfare, in Poyago-Theotoky J. (Ed.), **R&D Cooperation: Theory and Practice**, Macmillan, London, forthcoming.

De Fraja, G., 1993, Stategic Spillovers in Patent Races, **International Journal of Industrial Organization** 11, 139-146.

Delbono, F. and Denicolo, V., 1990, R&D-investment in a Symmetric and Homogeneous Oligopoly: Bertrand vs. Cournot, **International Journal of Industrial Organization** 8, 297-314.

Delbono, F. and Denicolo, V., 1991, Incentives to Innovate in a Cournot Oligopoly, **The Quarterly Journal of Economics**, 951-961.

Frey, B.S. and Eichenberger, R., 1993, American and European Economics and Economists, **The Journal of Economic Perspectives** 7, 185-193.

Friedman, J.W., 1983, Advertising and Oligopolistic Equilibrium, **Bell Journal of Economics** 14, 464-473.

Garvin, D.A., 1983, Building a Learning Organisation, **Harvard Business Review,** 78-91.

Griliches, Z., 1992, The Search for R&D Spillovers, **The Scandinavian Journal of Economics** 94, 29-47.

Harabi, N., 1995, Channels of R&D Spillovers: An Empirical Investigation, Arbeitspapier 37, Wirtschaftswissenschaftliches Institut der Universität Zurich.

Henderson, R. 1994, Managing Innovation in the Information Age, **Harvard Business Review** , 100-105.

Jacquemin A. and Soete L.,1994, Co-operation in R&D, Efficiency and European Policy, **European Review** 2, 65-72.

Jaffe, A.B., 1986, Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value, **The American Economic Review** 76, 984-1001.

Jewkes, J., Sawyers, D. and Stillerman, R., 1958, **The Sources of Invention**, Macmillan, London.

Kamien, M.I. and Zang, I., 1993, Competing Research Joint Ventures, **Journal of Economics and Management Strategy** 2, 23-39.

Kamien, M.I., Müller, E. and Zang, I., 1992, Research Joint Ventures and R&D Cartels, **The American Economic Review** 82, 1293-1306.

Kamien, M.I. and Schwartz, N.L., 1976, On the Degree of Rivalry for Maximum Innovative Activity, **Quarterly Journal of Economics** 90, 245-260.

Katz, M.L., 1986, An analysis of Cooperative Research and Development, **The Rand Journal of Economics** 17, 527-543.

Kesteloot, K. and De Bondt, R., 1993, Demand-Creating R&D in a Symmetric Oligopoly, **Economics of Innovation and New Technology** 2, 171-183.

Kesteloot, K. and Veugelers, R., 1995, Stable R&D Cooperation with Spillovers, **Journal of Economics & Management Strategy**, forthcoming.

Leahy, D., and Neary, J.P., 1995, Public Policy towards R&D in Oligopolistic Industries, paper prepared for CEPR Workshop in R&D Spillovers.

Lee, T. and Wilde, L.L., 1980, Market Structure and Innovation: A Reformulation, **The Quarterly Journal of Economics** 94, 429-436.

Lee, T. ,K., 1986, Strategic Commitment with R&D. The Case of Bertrand Competition, **Economics Letters** 21, 375-378.

Levin, R., Klevorick, A., Nelson, R. and Winter, S., 1987, Appropriating the Returns from Industrial Research and Development, **Brookings Papers on Economic Activity** 3, 783-831.

Levin, R. and Reiss, P., 1988, Cost Reducing and Demand Creating R&D with Spillovers, **The Rand Journal of Economics** 19, 538-556.

Loury, G.C., 1979, Market Structure and Innovation, **The Quarterly Journal of Economics** 93, 395-410.

Mansfield, E., 1985, How rapidly does New Industrial Technology leak out?, **The Journal of Industrial Economics** 34, 217-223.

Motta, M., 1992, Cooperative R&D and Vertical Product Differentiation, **International Journal of Industrial Organization** 10, 643-661.

Nakao, T, 1982, Product Quality and Market Structure, **Bell Journal of Economics** 13, 133-142.

Nelson, R.R., 1986, R&D,Innovation and Public Policy: Institutions Supporting Technical Advance in Industry, **AEA Papers and Proceedings** 76, 186-189.

Pérez-Castrillo, D.J. and Sandonis J, 1994, Disclosure of Know-how in Research Joint Ventures, Universitat autonoma de Barcelona, Discussion Paper.

Poyago-Theotoky J., 1995, Equilibrium and Optimal Size of of Research Joint Venture in an Oligopoly with Spillovers, **The Journal of Industrial Economics** 43, 209-225.

Reinganum, J.F., 1981, Dynamic Games of Innovation, **Journal of Economic Theory** 25, 21-41.

Reinganum, J.F., 1983, Uncertain Innovation and the Persistence of Monopoly, **The American Economic Review** 73, 741-748.

Reinganum, J.F., 1984, Microneconomics of Innovation and Productivity Growth: Practical Implications of Game Theoretic Models of R&D, **The American Economic Review** 74, 61-66.

Reinganum, J.F., 1985, A Two-Stage Model of Research and Development with Endogenous Second-Mover Advantages, **International Journal of Industrial Organization** 3, 275-292.

Reinganum, J.F., 1989, The Timing of Innovation: Research, Development and Diffusion, in Schmalensee, R. and Willig, R.D. (Eds.), **Handbook of Industrial Organization**, vol. I, Elsevier Science Publishers Amsterdam, 849-908.

Roberts, M. and Samuelson, L., 1988, An Empirical Analysis of Dynamic, Nonprice Competition in an Oligopolistic Industry, **The Rand Journal of Economics** 19, 200-220.

Rosen, R.J., 1991, Research and Development with Asymmetric Firm Sizes, **The Rand Journal of Economics** 22, 411-429.

Rosenkranz, S., 1995, Innovation and Cooperation under Vertical Product Differentiation, **International Journal of Industrial Organization** 13, 1-22.

Ruff, L.E., 1969, Research and Technological Progress in a Cournot Economy, **Journal of Economic Theory** 1, 397-415.

Salant, S.W., Switzer, S. and Reynolds, R.J., 1983, Losses from Horizontal Mergers: The Effects of an Exogenous Change in Industry Structure on Cournot-Nash Equilibrium, **The Quarterly Journal of Economics** 98, 185-199.

Schmalensee, R., 1976, A Model of Promotional Competition in Oligopoly, **The Review of Economic Studies** 43, 493-507.

Schnaars, S.P., 1994**, Managing Imitation Strategies**, Free Press, New York.

Schumpeter, J., 1970 (1943), **Capitalism, Socialism and Democracy**, Unwin University Books London.

Simpson, R.D. and Vonortas, N.S., 1994, Cournot Equilibrium with Imperfectly Appropriable R&D, **The Journal of Industrial Economics** 42, 79-92.

Spence, M., 1984, Cost Reduction, Competition and Industry Performance, **Econometrica** 52, 101-121.

Stenbacka, R. and M.M. Tombak, 1995, Technology Policy and the Organization of R&D, Working paper University of Helsinki and Helsinki School of Economics.

Steurs, G., 1995, Inter-industry R&D Spillovers: What difference do they make ?, **International Journal of Industrial Organization** 13, 249-276.

Stewart M.B., 1983, Noncooperative Oligopoly and Preemptive Innovation without winner-take-all, **The Quarterly Journal of Economics** 98, 681-694.

Sutton, J, 1992, **Sunk Costs and Market Structure**, The MIT Press, Cambridge.

Suzumura, K., 1992, Cooperative and Noncooperative R&D in Oligopoly with Spillovers, **American Economic Review** 82, 1307-1320.

Taylor, W., 1990, The Business of Innovation, **Harvard Business Review**, 97-106.

Tushman, M.L. and P. Anderson, 1986, Technological Discontinuities and Organizational Environments, **Adminstrative Science Quarterly** 31, 439-486.

Van Cayseele, P., 1987, Economies of Scope in Research and Development, **Journal of Economics (Zeitschrift für Nationalökonomie)** 47, 273-285.

Vergauwen, Ph., 1995, Strategic Information Sharing: What if markets Become Fuzzier ?, Katholieke Universiteit Leuven, working paper.

Veugelers, R. and Kesteloot, K., 1994, On the Design of Stable Joint Ventures, **European Economic Review** 38, 1799-1815.

Vonortas, N.S., 1994, Inter-Firm Cooperation in Imperfectly Appropriable Research, **International Journal of Industrial Organization** 12, 413-435.

Young, A., 1993, Substitution and Complementarity in Endogenous Innovation, **The Quarterly Journal of Economics**, 775-807.