Contingencies of innovative networks: A case study of successful interfirm R & D collaboration *

Jürgen Häusler, Hans-Willy Hohn and Susanne Lütz
Max-Planck-Institut für Gesellschaftsforschung, Lothringer Strasse 78, D-5000 Koln 1, Germany

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Trust among partners is an essential prerequisite in interfirm R & D collaboration. The paper deals with this question analysing the preconditions under which the establishment of trust among companies becomes possible. The case study of a very successful cooperative research project reveals trust-building as a modular, cascade-like process. Initially a wider scientific-technical network was established including all industrial and scientific actors who could be potentially interested in solving the technological problem at hand. The process ended with a smaller group of researchers from a few companies and scientific institutes cooperating in a government-sponsored R & D project. At each stage of this highly contingent process the intervention of public officials helped rendering cooperation successful.

1. Introduction: Networks in industrial R & D

"Strategic alliances for global markets" [1] – industrial cooperation is almost unanimously considered vital to a company's survival. Furthermore, interfirm networks are perceived as a major source of a nation's competitive strength. Conversely, industry's lack of interest or ability to engage in interfirm cooperative arrangements is repeatedly presented as a powerful explanation of nations' difficulties in "regaining the productive edge" (Dertouzos [16, p. 94]).

Not surprisingly, then, networks have also become a focal issue in the debate on industrial innovation. [2] The ascent of networks as a central topic in the literature on innovation has been accompanied by proposals for a redefinition of the concept of innovation. It is truly common knowledge by now that traditional "linear" models of innovation, in which basic research supports applied research producing results then used in development efforts, have become obsolete. New models must be able to incorporate notions such as feedback between scientific research, technical development and production, the simultaneousness of research and development activities, the interactive nature of innovation processes and the interdependence between various actors in industrial R & D [29,37,41,50]. In organizational terms, such "interactive" or "circular" models of innovation presume an institutional structure of innovation that is extremely variegated and involves a complex network of backward, forward, horizontal and lateral relationships and linkages within and among firms and organizations such as universities [56].

This reconceptualization of the innovation process needs to be complemented by a search for adequate ways to establish appropriate links between all the actors involved in related innovative activities. Market mechanisms as well as hier-

Correspondence to: Jürgen Häusler, Hans-Willy Hohn and Susanne Lütz, Max-Planck-Institut für Gesellschaftsforschung, Lothringer Strasse 78, D-5000 Koln 1, Germany.
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[1] EIRMA [19, p. 8]. EIRMA, the "European Industrial Research Management Association", was created in 1966 and has a membership of over 160 companies from 14 countries.

[2] See, most recently, the special issue of *Research Policy* on "Networks of Innovation" (20 (5) (October 1991) and among others: Ouchi and Bolton [38], Jorde and Teece [28] Hakansson [23], OECD [37].

archies are regularly perceived as being severely limited in their ability to govern complex intra- and interorganizational R & D activities in the industrial sector; instead, network forms of corporate interaction are expected to better facilitate technological innovation. Thus, from a theoretical perspective, protagonists of the "microeconomics of interaction" (such as Lundvall [31], Teece [49] and Dosi [18]) argue that innovation presupposes close interaction between, for example, producers and users. Only interaction based on reciprocal trust can reduce uncertainty in innovation processes sufficiently to allow a free flow of information and simultaneously limit opportunistic behavior. Successful interaction between research and industry is thus seen as requiring coordination processes within self-organized networks. In these networks, actors commit themselves to "lock-in" processes by establishing reciprocal trust and thereby render attempts to achieve unfair advantages costly and opportunistic behavior difficult. It is postulated, in other words, that intelligent behavior presupposes self-commitment based on trust and that learning requires stable relationships between partners. Both the "microeconomics of innovation" and the network approach applied to R & D and technology transfer generally remain, however, at the level of postulating needs and functional requirements. The question concerning the preconditions under which the establishment of trust among companies becomes possible remains widely unanswered.

Evidence supporting an increasing need for interfirm cooperation in innovation processes has been provided by an increasing number of studies which have identified the existence of a variety of cooperative arrangements in industrial innovation processes. In an economic environment where innovations tend to be increasingly costly and where the timing of market entry appears to be increasingly critical for the commercial success of innovations, *interfirm cooperation* is seen as the most promising way to reduce the risks and costs associated with industrial R & D and to increase the speed of R & D activities. Furthermore, because of the complexity as well as the interdisciplinary or trans-sectoral character of an increasing number of innovations, firms find themselves in a "capability squeeze" [20, p. 143]. Consequently, even the largest and most diversified corporations need to collaborate in R & D in order to gain access to complementary know-how. [3] Along these lines, companies' absorptive capacity or ability to exploit external knowledge becomes an increasingly critical factor for innovativeness. Especially in periods or in sectors where the integration of know-how requires results from more basic research than companies tend to do internally, close cooperation between companies and scientific institutions increases in importance.

On the whole, the literature tends to give a rather positive image of collaborative research. In sharp contrast, critical evaluations of failures in collaborative R & D are almost non-existent, although these failures can certainly be expected to exist in reality. Similarly, well-researched examples of smooth and efficient interfirm R & D collaboration are hard to come by, as well.

However, neither the scientific community's growing awareness of the existence of networks in the industrial innovation process nor the increasing empirical evidence that cooperative arrangements are becoming more numerous and/or more important in industrial R & D should lead to hasty conclusions. In the midst of a period of widespread, and frequently uncritical, fascination with the "cooperation phenomenon" in industrial R & D [36], it appears necessary to recall that companies by and large favor internal over external R & D. [4] Although a sound rationale for cooperative research has been established in a large number of analyses and although numerous empirical studies have revealed companies' motivations for participating in collaborative research

[3] See, among many others, Teece [50, p. 37 ff.] and the literature review in OECD [37, pp. 105–140]. The most ambitious data bank on R & D-related interfirm collaborations is assembled at the University of Limburg (MERIT); see, for example, Hagedoorn and Schakenraad [22].

[4] Based on the most extensive empirical study of R & D cooperations in German industry to date, Täger [48, p. 18] reports that 96% of the companies in his survey conducted their R & D predominantly in-house, 36% used external R & D contracts and 26% cooperated with other companies (multiple answers were possible). A survey by the Agency for Science and Technology reported in 1985 that among Japanese firms 20% had R & D-related links with other firms and/or scientific institutions; in 1980 the number was 13%, in 1990 the figure was expected to reach 26% [3, p. 2].

projects, [5] the cooperation phenomenon seems to be far from ubiquitous in the world of industrial innovation.

In quantitative terms, German companies, for example, spend less than 10 percent of their R & D budgets on external R & D. [6] Whereas all large industrial companies are reported to participate in R & D collaborations, only a third of the small and medium-sized industrial enterprises appear to be doing the same [34, P. 126; 48, p. 21]. Companies' willingness to cooperate in R & D differs considerably between industrial sectors [7] (and presumably countries [8]) and is quite low in certain sectors. Finally, most companies tend to prefer internal R & D especially in those technological fields they consider to be core technologies of strategic importance to their long-term success. Conversely, cooperative R & D seems more common in cases where companies are forced or choose to test possibilities for diversifying into new technological areas [11, p. 34]. To sum up, it should be noted that the question whether a company should commit R & D resources to cooperation with others is *not trivial*. "There are good reasons *against* cooperation" [19, p. 13, italics added].

There are many reasons which help to explain both the relative reluctance of companies to get involved in collaborative R & D and the variation between different industrial sectors, different countries and/or enterprises of different size. External R & D cooperation is frequently perceived as a threat or a risk not only by R & D departments (the well-known "not-invented-here" syndrome) but also by management (fear of opportunism, [9] leakage, [10] or other reasons. [11]). Last but not least, companies can have come to the conclusion, based on past experience with joint industrial R & D projects, that because cooperative R & D activities are not likely to succeed, they are a second-best solution. Thus, companies certainly debate the feasibility of R & D-related cooperation on the premise that establishing a great number of good reasons for cooperation does not mean that such alliances are easy to build and to manage or are always successful.

From a company perspective, finding reasons for cooperation by no means suffices to make a case for cooperation. Once the question "*why* cooperate?" is answered, the next and most pressing question becomes "*how* to cooperate" or, in other words, how are successful R & D-related interfirm collaborations built? Systematically, critical conditions can be identified along two dimensions: *horizontally* where primarily distributional issues between the cooperating companies are dealt with and *vertically* where the relationship between management and R & D personnel involved in joint projects is defined.

Equality among partners is usually considered essential for efficient interfirm cooperation [5]. The stability of cooperative arrangements has

[5] The motivations most often cited are risk-sharing, cost-sharing, establishment of standards, complementary and strategic motivations (entry to foreign markets, surmounting regulatory or licensing barriers, precursor for pursuit of mergers or acquisitions) [21, p. 1991]; see also EIRMA [19]. Usually, the search for *technological complementarities* is cited as the most frequent – and promising – motive [7, p. 21]. The growing importance of the "*convergence* in technologies" [35, p. 11, italics in original] creates both the opportunity and the need to exploit technological complementarities.

[6] This figure increased steadily between 1969 (3.6%) and 1983 (9.8%) but has been apparently leveling off or even falling in the most recent years (1985: 9.0%, 1987: 8.4%, 1989: 9.2%) [25, p. 74]; [46, p. 50]; [47, p. 46]. In 1986, a survey among 50 large international industrial companies showed that only four companies spent more than 10% of their research budgets in research alliances, eight spent 5–10%, eleven 1–5% and nine companies spent less than 1% [19, p. 50].

[7] According to the "official" statistics of industrial R & D in Germany, in 1989 industrial sectors devoted between 1.8% and 9.1% of R & D resources to external R & D [47, p. 46].

[8] According to a *Los Angeles Times* survey, among US companies 17% believe alliances to be useful, 3% are convinced that they are dangerous; in contrast, among Japanese companies only 4% view alliances as potentially dangerous, whereas 74% are convinced that alliances are very effective (*Wirtschaftswoche*, 14 June 1991).

[9] This appears to represent the dominant perspective in which US analysts view joint R & D activities with Japanese companies; Reich and Menkin [40, p. 85], for example, consider such collaborations to represent "extended dance(s) of death" for participating US companies.

[10] In spite of recent attempts by a number of economic analysts to demonstrate that leakages accompanying informal know-how trading are very well in the companies' interests [13,26,44].

[11] According to Täger [48, p. 77], 68% of all companies, when asked to name the main disadvantages of R & D cooperation, say that they are afraid to reveal their innovation strategies in R & D collaborations, 68% are worried about their technological independence and 63% expect previously established internal know-how to leak to other companies.

been found to depend on many factors being equal (or similar) for each partner: the interests in the cooperation, background knowledge, contributions to the joint project and gains from the cooperation [48]. Equality is perceived to be necessary in order to prevent "a permanent power struggle, which guarantees failure" [19, p. 12]. Unequal distribution of R & D resources, for one thing, tends to eventually lead to disruptive tensions between partners. It is feared that partners judging themselves to be in a position of weakness will concentrate their efforts on trying to balance the supposedly unequal relation and thereby disrupt joint efforts.

At the onset of a joint R & D project, equality among partners refers to both the degrees to which potential partners are interested in the establishment of the collaboration and to the potential contributions to the planned joint activity expected from each partner [5,48]. This alludes, first, to the fact that companies are required to establish sufficiently broad and qualified internal knowledge bases not only to be able to absorb external know-how [14] but also to be considered worthwhile partners by potential collaborators. Second, this implies that a great deal of knowledge about potential partners is required before companies feel inclined to join a collaboration. However, this process of "partner-identification" [10, p. 29] in the context of R & D regularly proves to be very difficult and thus "adds an additional dimension of uncertainty" [21]. Pre-existing links between companies would certainly facilitate the process of identifying suitable partners for joint R & D projects. If, however, the research project involves finding partners in technological fields that are just beginning to be explored, pre-existing links might not only be of little help, but, considering the "path-dependency" of network structures, might even obstruct the process of establishing necessary new links.

Providing equal or similar contributions to the joint project is also considered important for equality among partners. Agreements, therefore, "should establish specific performance requirements" [24, p. 136]. However, as was the case with evaluating the pertinent background knowledge of potential partners, an ex ante assessment of companies' expected contributions to the joint activity is bound to pose great difficulties in joint R & D projects. In a number of case studies companies were found to have developed practical solutions to both problems of distributive fairness. Companies apparently act on the basis that they cannot always expect to arrive at detailed analyses proving equality among the partners' respective pools of knowledge prior to the joint activity: "Partners rarely begin from a positions of equality though it is *sometimes simpler to assume this*" [21, p. 10, italics added]. Furthermore, agreements on joint R & D projects tend to remain rather vague about the valuation of expected contributions from all partners involved.

This stands in sharp contrast to frequent propositions in the literature according to which "agreements and contracts covering the collaboration must be clear and detailed" [19, p. 30]. On the one hand, the vagueness certainly results from an inability to define ex ante precise workplans for most R & D projects and thus establish precisely the contributions from all partners involved. In order to allow for mutual learning processes at the level of the actual joint R & D project and to retain enough flexibility for the collaboration to adapt to change, contracts have to remain open to a certain degree. They are not considered the adequate governance mechanism at the level of day-to-day work in the laboratory within R & D collaboration. Instead, their proper role is seen in arranging for workable "exit conditions" [21]. [12]

Somewhat surprisingly, a high degree of relying on the trustworthiness of partners also seems to prevail in regulating the ownership of results of joint R & D projects. This comes as a surprise since there is widespread theoretical agreement on the vital importance of the issue of industrial property rights.

Recurrently, the existence of precise goals for a joint activity is seen as a prerequisite for successful cooperation [5] in three different respects. It is suggested that companies should arrive internally at a precise definition of their own goals before entering a collaboration. At the interfirm level, efforts to precisely define the common goal

[12] In case of failure the standard procedure seems to follow the "you cut, I choose" rule: One of the partners (partner A, usually the smaller one) gets the first choice to acquire the joint venture (or product) at a price set by the other partner (partner B); should A choose not to buy, then B has to buy at the price he previously set.

are valuable for two reasons. First, they force both partners to reveal their respective interests to each other openly and explicitly. Second, based on the assumption of generally diverging goals between the partners, these efforts can serve to determine areas where partners' goals "overlap" and thus improve conditions for defining tasks for meaningful cooperation.

Within companies, the ability to control the activities of company members in the joint project presupposes the existence of clear goals for the company and for the collaborative activity. Well-defined goals, possibly disaggregated into a series of "milestones", open the way for participating companies' management to efficiently oversee activities in the project and repeatedly re-evaluate participation.

Close monitoring would seem necessary because R & D-related cooperation with other firms (or scientific institutions) entails the danger of leakage. External cooperation requires that special attention be paid to ensuring the transfer of technological innovations created within the joint project, and the danger that "a collaboration removed from the main body of the firm's activities risks losing touch with market priorities" must be taken into account [21, p. 10]. These hazards are likely to lead companies to try to achieve a rather high degree of control over their employees' activities in a joint project [24].

Within the context of collaborative research projects, however, management's definition of precise goals and, interrelatedly, its exercise of tight control over staff members involved in the collaboration seems very unlikely, in spite of the fact that these elements are frequently cited in the management literature as being critical preconditions for successful cooperation (by practitioners and theorists alike). Defining precise goals that might guide the work within the joint project may prove to be nearly impossible in research projects concerned with non-routine tasks and aiming at more than an incremental improvement of established products and processes.

Furthermore, a seemingly trivial, albeit portentous fact that is often neglected in the literature needs to be recognized. The activities within the interfirm R & D collaboration that are intended to lead to the aspired innovation take place at the level of the group of researchers representing the participating companies. At this *production level*, open and uncalculating cooperation among researchers is vital for the success of innovative activities. The dilemma management thus faces is evident: "Collegiality is a prerequisite for collaborative success. But *too much* collegiality should set off warning bells to senior managers" [24, p. 138, italics in original]. Apparently, management must learn to live with the fact that successful R & D cooperation requires researchers to develop dual loyalties. Faced with having to establish control mechanisms to prevent either unbalanced leakage or a neglect of market demands from occurring and, at the same time, being obliged to allow for sufficiently autonomous R & D personnel, company management is required to limit itself to "indicative instructions" [42].

The following analysis is set against this background of *rationales for* as well as *difficulties with* the formation and implementation of interfirm R & D collaboration as established within the discourse on R & D networks. This analysis attempts to shift attention to some of the more skeptical questions regarding the functioning of networks in industrial R & D. [13] Given that companies are frequently much more reluctant to participate in interfirm cooperative R & D activities than most prescriptive or functionalist analyses would lead us to expect, it seems imperative to attempt to reveal some of the central *intra- and interorganizational preconditions* for successful R & D-related collaboration among firms. [14]

For detailed empirical evidence, the analysis depends to a great extent on a case study briefly summarized in section 2. [15] The interpretation of the case study focuses on critical aspects of interfirm R & D cooperation on three levels. First,

[13] For a similar perspective concerning, however, the discourse on "strategic alliances" between companies in more general terms, see Séguin and Denis [45].

[14] This analysis is broadly based on three projects presently underway at the MPI für Gesellschaftsforschung that deal with, respectively, (i) the relation between industrial research and government intervention, (ii) the science–industry interface and differences among technology-transfer institutions, and, finally, (iii) R & D cooperation in government-sponsored research programmes. Edgar Grande and Jürgen Häusler, Hans-Willy Hohn and Susanne Lütz are, respectively, conducting these projects.

[15] For further details see the forthcoming doctoral dissertation by Susanne Lütz (*Verbundforschung als Förderinstrument des BMFT*).

the establishment of a scientific-technical network is described in some detail (section 3). It is shown that the establishment of the network facilitates the formation of R & D collaboration (section 4), in which a smaller number of actors based on quite diverse yet compatible interests pursue the idea of a joint R & D project. An analysis of the structure of collaborative R & D projects (section 5) follows, initially suggesting that two levels of interaction between the participating companies be distinguished: The level of the individual firms collaborating and the level of the research group actually forming a joint R & D project. Finally, a cascade-like model of interfirm R & D collaboration is used to illustrate the delicate social dynamics during the final stage of R & D collaboration within this interorganizational network form (section 6).

2. A case study: "Adhesion as a production technology"

The research project "Adhesion as a Production Technology" ("Produktionstechnologie Kleben") was deemed successful as it proved the applicability of adhesives in certain areas of industrial production processes where welding technologies had traditionally dominated. After a preparatory phase, research within the project was conducted from July 1987 to the end of 1990. The project was carried out under the auspices of a government research programme on production technologies sponsored by the Federal Ministry for Research and Technology (BMFT, Bundesministerium für Forschung und Technologie). When the BMFT initiated this programme in 1984, it for the first time expressly supported

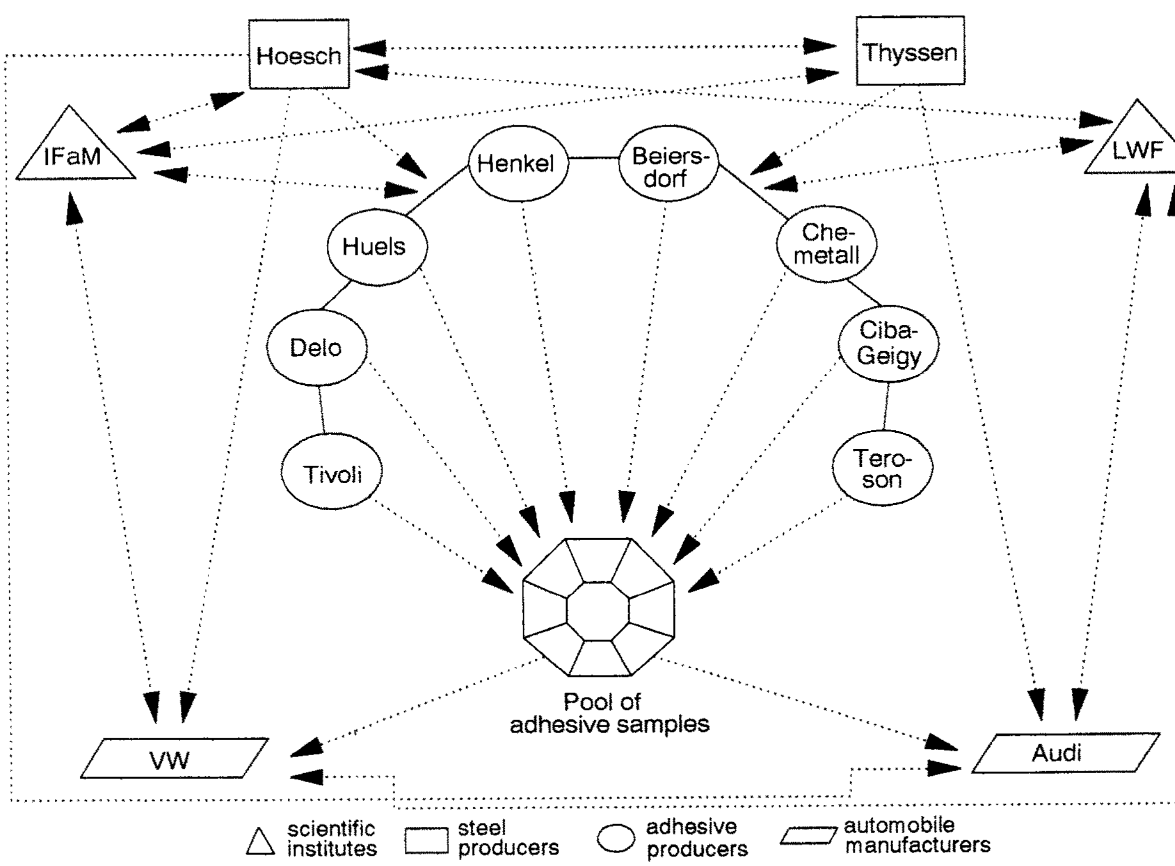

Fig. 1. Participants in the research project "Adhesion as a Production Technology".

collaborative R & D as an instrument for promoting cooperation between research institutes and industry ("Förderinstrument Verbundforschung"); a percentage of the programme's funds were earmarked for a research project incorporating cooperation in R & D between industrial companies and scientific institutions. Research institutes and several competing adhesive producers were among the participants along with steel producers and automobile manufacturers. The project cost a total of DM 20 million, 9.8 million of which was provided by the ministry. In addition to the BMFT, the agency implementing the government research program ("Projektträger Fertigungstechnik") was an integral part of the project well beyond the financial contributions mentioned above.

At the onset of the project, the use of adhesion as a mass-production technology was perceived as being unduly limited. The comparative advantages of adhesion technologies were postulated, including their success in joining many different materials to produce very sturdy, compact and non-corrosive connections. A lack of general construction rules, uncertainty regarding their performance in repetitive mass-production processes and regarding aging characteristics and, finally, the need for a scientifically sound understanding of the phenomenon "adhesion" were seen as some of the reasons limiting the application of adhesives in industrial production. The project thus aimed at making adhesion in production processes more predictable and at establishing a systematic account of material and process parameters that influence performance. The project successfully demonstrated the technical feasibility of adhesion as a mass-production technology, established a sound body of chemical and physical knowledge and substantiated pilot applications under actual working conditions. It was shown that adhesion is a viable alternative to welding in the production of automobile bodies.

These results were achieved within a collaborative R & D project in which two research institutes (IFaM, Fraunhofer-Institut für Angewandte Materialforschung in Bremen and LWF, Laboratorium für Werkstoff- und Fügetechnik at Paderborn University) did basic research and provided testing facilities. Two steel producers (Hoesch and Thyssen) provided the materials to be connected, and eight adhesives producers individually developed a great number of adhesives which were tested by two automobile producers (VW and Audi), thereby introducing a users' perspective (see fig. 1). Thus, interdependencies between industrial partners existed horizontally (primarily between competing adhesive producers) and vertically (between suppliers of steel, producers of adhesives and users in the automobile industry). Forms of collaboration included the common definition of goals and workplans, jointly agreed-upon division of labor with R & D competitively conducted in the respective company laboratories, joint use of testing facilities and interactive evaluation of performances and definitions of necessary adaptations. Thus, although R & D was mainly conducted in separate company labs, the actual outcome of the research project was essentially the result of not only a high degree of interaction, dense communication, joint decision-making, feedback between individual R & D efforts, and joint evaluations of results, but also repeated reinterpretations of promising paths for further research. It therefore seems quite justified to speak of a collaborative R & D project.

In a more analytical perspective, the following interpretation of this case of successful interfirm R & D collaboration will focus on the mechanisms at work in the establishment of a technical-scientific network, the interests and conflicts involved in the formation of a collaborative R & D project and the social dynamics on the level of the interpersonal network where research efforts were actually carried out.

3. Establishing a scientific-technical network

As noted in the introduction, recent contributions to innovation theory stress the point that both the complexity and the interdisciplinary nature of an increasing number of innovations increase the probability of corporations entering into R & D-related collaboration with other companies and with scientific institutions in order to acquire access to the complementary knowledge they require. To accomplish the goal of establishing adhesion as a viable alternative to welding in industrial mass-production processes, it proved necessary to combine knowledge accruing at different stages of the innovation process, since very fundamental knowledge concerning the principles of adhesion was considered to be as essential as applied knowledge about the use of adhesives in actual production processes. At the same time, acquiring knowledge from several scientific disciplines proved necessary. Chemical know-how about the composition of adhesives and adhesive joints was called for as well as engineering know-how about adhesives' practical applications. Also, at this early stage of the process and this general level of initially bringing together interested parties within a communication network, activities had to transcend well beyond the scope of conventional R & D projects. These included developing new testing methods, setting standards to facilitate the selection of adhesives and ensuring their quality and, last but not least, creating curricula for vocational training in the use of adhesives in all areas of production [8,9].

Furthermore, the ultimate success of the innovation activities was considered to depend heavily upon the early and wide diffusion of the new product or production technology. The required acceptance among potential users had to be secured in direct competition with the established technology, so that coordination among actors beyond the narrowly defined R & D sector was viewed as being very important. Consequently, activities were initially aimed at bringing together in a loosely coupled network all relevant actors from different organizations and with different perceptions, i.e. experts from scientific institutions, producers and users of adhesives, business associations, training institutions and organizations which establish standards.

As actors in the adhesives' sector found themselves in an *institutionally highly fragmented environment*, "networking" encountered considerable difficulties. The creation of links between a large number of relevant actors within this environment posed two problems. On the one hand, it required securing connections between previously unrelated actors, such as chemical research institutes and users of adhesives. On the other hand, it required reorganizing existing relationships, such as the close bilateral links between engineering institutes and users or between producers and users of adhesives. If the knowledge and experience of these disparate actors was to be synthesized, these relations had to be integrated into, and thereby become sub-components of, the wider network.

The existence of links between all the members of the group of interdependent actors could not be presupposed in our case study. This can be demonstrated by describing the scientific landscape in the adhesives sector at the beginning of the 1980s. There were a number of scientific institutes dealing with the problem of adhesive bonding, none of which was, however, dealing with adhesion exclusively. Of the two types of institutes mainly involved, chemical institutes conducted basic research on the principles of composition of adhesives (if cooperation with industrial partners existed, it involved bilateral contacts with producers of adhesives) and engineering-oriented institutes focused on the technology of welding, looking at problems of adhesive bonding only in connection with other available joining technologies. These latter institutes, nonetheless, played the dominant role in the scientific sector of adhesives. They also maintained close bilateral relationships with the users of adhesives, whose primary interest was centered on practical and application-oriented knowledge.

Fragmentation also characterized the field of business and scientific-technological associations working in the adhesive sector. Important platforms enabling scientists from institutes or the industrial sector to meet informally and discuss questions relating to the evaluation and advancement of certain technologies, these associations could address such issues as coordinating related R & D projects or conceptualizing specialized training seminars. In the field of adhesives there were two relevant associations, each representing a segment of the sector. Surprisingly, the German Association for Welding Technologies Deutscher Verband für Schweißtechnik, (DVS) with its subcommittees on adhesion had to be seen as the dominant association in the adhesives sector. The DVS primarily represented engineers who worked either in the user industries or in institutes in which research activities focused on welding problems. The second relevant association was the DECHEMA, primarily representing chemists working for adhesive suppliers or chemical research institutes.

In conclusion, attempts in the early 1980s to form a network of technical experts interested in the advancement of adhesion as a production technology faced an adhesives sector institutionally fragmented along several dimensions. Fragmentation characterized the relationships between scientific disciplines and between activities at different stages of the innovation process.

Integrating activities throughout these areas was perceived to be necessary in order to develop and lobby for a sectoral innovation strategy aimed at establishing adhesion as a common production technology, especially in the automobile sector. Thus, the highly fragmented nature of the adhesives' sector in the early 1980s contrasted sharply with the perceived need for synthesizing complementary knowledge and coordinating the activities of a large number of actors.

Efforts to overcome the state of fragmentation resulted in a surprisingly high degree of institutionalization. Following the initial foundation of a working group, participants in this originally very loosely coupled network readily agreed upon the necessity of a more firmly institutionalized platform for adhesion technologies. The working group members just as readily agreed upon the idea of becoming incorporated into one of the scientific-technical associations within the field. After much conflict, DECHEMA was finally chosen. An institutional backbone of a scientific-technical network in the adhesive sector was thus created.

A closer examination of the process of institutionalizing a formerly highly fragmented environment reveals the importance of a *mobilizer* [32]. The mobilizer in our case was certainly accepted as a professional expert displaying a high degree of competence in the field of adhesion. His reputation was, to a large degree, based upon previous interactions with a number of the potential members of the future network. Also, his record helped certify his trustworthiness, which was additionally reinforced by the existence of common background expectations among researchers from technical universities, Fraunhofer Institutes and industrial laboratories in the field of applied research. The mobilizer was also considered to be a "linking pin" to other networks. For one thing, this high degree of connectedness enabled the mobilizer to convincingly create the impression that he had access to other networks, from which support and, more specifically, financial resources (in our case public funding) could be drawn. Finally, the mobilizer was perceived to be a partner who could be relied upon to passionately articulate his ideas based upon his very clear individual interest in the collective endeavor's success at the network level.

The mobilizer's personal interests (and competencies) were well in line with the institutional self-interests of the organization he represented, an institute of the Fraunhofer Society (Fraunhofer-Gesellschaft, FhG). The FhG perceives itself as a research company competing in the market for contract R & D. Institutes within the FhG depend largely on external funding coming mostly from industry. Therefore, they are continuously engaged in initiating and implementing collaborative R & D projects. As well-known experts in their respective fields, their members tend to have a large number of contacts with technicians in industry as well as with public officials and thus frequently serve as network managers, like the mobilizer in our case study (on the FhG in general see Hohn and Schimank [27, pp. 173–231]).

From his own point of view, the mobilizer's first task in establishing the network was to find followers sharing his interest in advancing adhesion technologies. The first to join him in the process of "*enrolement*" [30] were other research institutes he had just finished cooperating with in a joint research project financed by the BMFT. They joined the mobilizer in organizing a conference to present the results of their cooperative R & D project and to document the state of the art in the field of adhesive bonding. It was not until then that the scientists were joined by industrial actors. The cooperation at this stage was based on a general understanding that a collaborative effort to explore adhesive bonding's potential applications in areas where welding had long been the dominant joining technology would be worthwhile and very promising [12]. As described above, the collaboration was then institutionalized in the form of a joint sub-committee within the DECHEMA.

A platform providing a firmly established infrastructure for the future was thus created which could be, and was, used not only for facilitating R & D cooperation but also for coordinating the various activities necessary for advancing adhesion technology, such as specifying standards and conceptualizing curricula for specialized training. From that time on, the sub-committee constituted the core of a developing technical community in the adhesives sector, allowing for the first time an interdisciplinary and intersectoral discussion on problems of adhesive bonding among chemists and mechanical engineers. A new forum for technicians and scientists from research institutes and industrial R & D labs, the sub-committee provided an institutional foundation for the development of a community of experts. The promotion of adhesion as a mass-production technology was the overall objective guiding the activities of the network and provided the underlying basis of agreement, or "mega-goal" [33], as well as the basis for establishing a reputation and trust among members in the network. Since there was now an opportunity to engage in "truth games" [43], it was possible to agree upon permissible strategies and upon the rules governing succeeding games, and each actor was able to obtain more complete information about respectively strategic options and payoffs.

4. Forming an R & D collaboration

Within the context of the newly established scientific-technical network, the idea of forming a collaborative R & D project developed. The existence of the network facilitated the establishment of the R & D project in several ways. Partner identification was made very easy, most of those who became R & D project partners had already been members of the network. The experiences gained from interactions in the network also created a degree of empathy [43] among potential partners in the project which it would certainly have been harder to establish otherwise.

Defining the common goal of a planned joint endeavor is a process to which utmost importance is attached in the literature and which is vital for understanding potential partners' strategic options. This proved to be fairly easy in our case, because a shared vision regarding the technological challenges facing the group as well as the technological paths open to it had already been developed interactively within the larger network. Finally, the fact that the proposal for the research project was developed within the network and was, consequently, advocated by all the relevant experts in the network was largely perceived to have been decisive for the project's being able to receive government support for the joint R & D activity. As the form in which companies and institutes collaborated changed from a large "permanent functional network" to a smaller "temporary project network" or "action set" [33], the level of commitment required from the participants increased considerably; consequently, the interests leading each partner to join the R & D project call for closer examination. [16]

It was the participating research institutes which primarily sought for and obtained financial resources. According to the stipulations in the public research programme on production technologies, funding for participating research institutes was to come from the government and, depending on how much of the institute's work was assessed as being application-oriented, the participating companies.

In a more strategic perspective, it appeared worthwhile for the institutes to acquire competencies in a very early phase in the development of an emerging technological trajectory with a promising future. To an extent, the existence of a potent scientific-technical network lobbying for the use of adhesives in mass-production processes provided sufficient testimony for a promising future. Even the institutes that had primarily concentrated on welding technologies subsequently developed at least a passive interest in participating in the collective effort to evaluate the potential of a rival joining technology. Basically, different institutes hoped to be able to put themselves in a good position for the time when competition for industrial orders in the emerging technological field would solidify.

When dealing with R & D collaboration, the management of industrial companies are primarily concerned with two interrelated sets of issues. First, there are decisions to be made concerning whether (or to what extent) a company is willing to participate in cooperative R & D activities. Motivations favoring collaboration as well as reasons for not cooperating and factors limiting the willingness to cooperate fall under this heading. Second, when it decides to enter a cooperative R & D project, management must arrange for

[16] The following statements about actors' perspectives and interests are based on in-depth non-standardized interviews conducted by Susanne Lütz with nearly all the participants in the project.

contractual agreements to be made which will ensure its company a fair (or just) share in the gains (or costs) of the endeavor. Mechanisms or arrangements to adequately regulate the distributional effects of cooperative R & D activities are the subject of interfirm bargaining processes at the managerial level.

Although it hardly suffices here to refer to the general motivations for companies' participation in collaborative research projects as they have been established in many analyses and empirical studies, it is helpful to recall that the search for technological complementarities is the most frequently cited motive; indeed, it appears to be the underlying motivation in our case, as well. Our case exemplifies a situation in which cooperative R & D becomes possible, if not necessary, because companies choose to, or are forced to, test possibilities for diversifying into new technological areas.

The *constellation of industrial partners* as it evolved in this project certainly fulfils the requirements of a research endeavor aimed at advancing a "radically" new technology in competition with an established technology while at the same time dependent on the successful integration of complementary know-how. The industrial partners in the project represented all the relevant stages of the value-added chain from steel (suppliers) to adhesives (producers) and automobile manufacturers (users). Moreover, the project involved several competitors at each stage of the value-added chain. This constellation made it possible to promote the integration of a full range of complementary perspectives into the innovation process and to safeguard against the domination of any one perspective, for example that of the powerful user. Furthermore, it encouraged competition among partners to strive continuously for better solutions.

This is not to say, however, that functional requirements or a generalized insight among partners into such functional requirements could be considered responsible for the evolving constellation of partners. Rather, initially diverse individual interests were rendered compatible in a process of bargaining among partners and subsequent redefinitions of individual interests as well as critical government interventions.

The participation of the *automobile industry* proved to be absolutely critical in assuring the collaboration of companies along the value-added chain as well as participation of competing adhesives producers. In a general way, the automobile industry as the potentially most attractive customer of adhesive bonding technologies perceived adhesion technologies as possibly being able to help improve the rigidity of the automobile body. As the tendency towards lightweight construction grew in the automobile industry, adhesives were seen as an intriguing possible solution to an increasingly pressing technological problem.

The use of this technology in mass-production processes, however, required a degree of certainty regarding the reproducibility and calculability of adhesive joints which was obtainable at that time; additional basic knowledge as well as solidly established testing methods were needed. These almost "radical" innovations were perceived to be too expensive and risky for a single firm. Cooperation among several partners in a joint R & D project which was in part publicly funded made it possible to spread risks and costs and, according to researchers in the automobile company, provided added legitimacy for the research endeavor in internal disputes on whether such research was worthwhile.

At the end of the project, the automobile manufacturers seemed to have benefited greatly from the fact that a large number of adhesives producers had participated in a competitive spirit. At the beginning, however, the manufacturers had wanted to keep the number of participants very small, one automobile firm suggested carrying out a joint project together with one adhesive producer, one steel producer and one research institute. For the scientific mobilizer, this posed a threat to the realization of his ambitious goal: There was a danger that the proposed constellation could cause one user's interest to become too dominant, thereby unduly restricting the necessary broadness of research efforts. The most he expected to come out of a project of such a limited scope was a mere incremental improvement of existing technologies.

In this critical situation, public actors intervened to facilitate the establishment of the originally planned R & D collaboration. This time, as had happened earlier in the development of the project, the intervention was not limited to creating an opportunity by announcing the readiness to fund a research project. Now, public representatives became more active and refused to finance the research activities of market leaders. Intending to distribute financial support among several firms in a particular industry, they forced the intended closed shop to open up and integrate competitors. Consequently, a larger number of adhesives manufacturers, steel producers and a second automobile manufacturer were integrated into the joint R & D project. Only later did the automobile companies recognize the advantage of being able to collaborate with several adhesives and steel suppliers and thereby compare the respective competencies and capabilities of a large number of potential suppliers.

The *steel producers* were primarily interested in preventing the raw material steel from being substituted by competing materials such as aluminum and plastics. For this reason, they had a basic interest in having steel included as a raw material in research endeavors aiming at advancing new joining technologies. As long as one of their major customers, i.e. the automobile industry, continued to use established joining technologies such as welding, the steel producers had no interest in lobbying for the wider use of adhesive bonding technologies. However, once an automobile manufacturer agreed to participate in a joint project that was designated to investigate the potential of new bonding technologies and to possibly apply these new technologies to new materials, the situation changed. Now the steel producers, too, were forced to get involved and had little choice but to consider it worthwhile to invest resources in a risky development.

Adhesives producers perceived the wider use of adhesive bonding technologies as an opportunity of diversify into a promising and attractive market. Solving numerous difficult technological problems which had hitherto prevented extended use, however, certainly necessitated long-term commitment, large financial resources and entailed technical as well as economic uncertainties. Until a major customer could be integrated into the R & D process and thereby specify users' requirements, the producers did not have enough information about the required performance specifications or about the market potential of the new product. When an attractive customer joined the R & D project, the adhesives producers' uncertainty on these two points diminished.

Those adhesives producers which already served as suppliers to the automobile industry particularly needed to join the R & D project once customers had joined. Pressure to include almost all adhesives producers expanded as soon as the planned trilateral project opened due to pressure from the government agencies financially supporting the R & D activities. In other words, once the other adhesive producers had the chance to participate in the project, they felt compelled to do so.

The survey of the literature on interfirm R & D collaboration presented in the introduction clearly demonstrates a widespread preoccupation with issues of distributional justice. Repeatedly, collaborating partners state that the success of cooperative arrangements depends upon equal or similar interests in the cooperation, background knowledge, contributions to the joint project and potential gains from the cooperation. To secure distributional fairness, contractual agreements must be sufficiently clear and detailed and are said to have to include specific goal definitions, specific performance requirements, etc.

In our case, none of this seems to be true. Regarding, for example, expected contributions from participants, the contract in our case study solely requires all participants to supply adequately qualified personnel, to provide these researchers with sufficient technical and other means so that deadlines can be met, to appoint a contact person, to dispatch employees to all project meetings and to "make all efforts to achieve all goals and provide all interfaces agreed upon" by all partners (our translation). Thus, our case study strongly supports those analysts who expect agreements on joint R & D projects to remain rather vague about the evaluation of the contributions expected from each partner, arguing that the attribution of specific contributions would prove too difficult and freer regimes would most likely work better [21]. As far as the level of day-to-day work activities on the R & D collaboration are concerned, researchers in the adhesion project saw contracts as being neither an adequate nor an important governance mechanism. They saw no relevance in the contract for guiding their R & D activities and referred to the contract merely as a "marriage contract" arranging for workable exit conditions.

5. The structure and social dynamics of an R & D collaboration

So far, our analysis has relied on a unitary actor model. In this section, a more complex conceptualization of the structure of interfirm R & D collaborations is applied which acknowledges the *multilevel* nature of interorganizational relationships [6]. Whereas company management needs to establish rules and regulations safeguarding their distributive claims, the research group can engage in cooperative R & D leading to successful innovations. Thereby, the coexistence of competitive and cooperative interaction orientations within a single interorganizational relationship becomes feasible.

This shows us that solving distribution conflicts, at least provisionally, is but one of the preconditions necessary for successful interfirm R & D collaboration. Cooperation among researchers in interfirm R & D collaboration constitutes a complicated game not only between the firms, but within firms between management and employees, too. Within interorganizational R & D collaboration, scientists and engineers perform "boundary spanning roles" [1]. They act as "organizational gatekeepers" [2,51,52], bargaining and making decisions on behalf of their respective organizations. Thus, organizations have to delegate competency in decision making to the actors in boundary-spanning roles, thereby becoming dependent on how the actors perform their role. Management's influence is widely reduced to the decision as to whether it is worthwhile to take part in a collaboration or not.

The most important problem arising out of this context is that scientists and engineers involved in collaborations cannot simply act as "honest brokers" of their firms. Rather, facing dual responsibilities, they play a "two-level game" [39]. At the first level they are involved in negotiations with external groups, made up in our case of other scientists and engineers. These negotiations may produce results which must then be ratified at the second level by their "constituencies", i.e. the delegating organizations.

This two-level nature of industrial collaborations constitutes a dilemma for the members of interorganizational working groups. As representatives of competing organizations they have to deal very cautiously with information concerning their firms' scientific and technical know-how. In game-theoretical terms, their "win-set" does not include a strategy of obtaining complete information at the first level. Every member of the interorganizational working group knows, or at least may know, that each member is obliged to withhold information. Thus, the conditions for setting up an efficiently working research team are highly contingent. The members of the group eye each other with distrust and view each other as free riders. Accordingly, cooperation would be impossible if all working-group members tried to maximize informational gains and minimize losses. The development of collaboration requires that members of the interorganizational group informally indicate their willingness to partly abandon or selectively keep their secrets. They must, in other words, establish a norm of *informational reciprocity* allowing them to surmount the obstacles of distrust and solve the problems associated with free riders.

On the other hand, the group's solidarity must have recognizable limits. The more successful the members of the research group are at solving the problems of distrust at the first level, the more they will be confronted with growing distrust at the second level. Given a certain degree of reciprocity at the interorganizational level, constituencies may come to expect the values and norms of the group to be in conflict with the values and norms of the firms taking part in the collaboration. As a consequence, the members of the research groups must not only strike a balance between solidarity and competition at the interorganizational level, but they must also reduce distrust within their organization as well. Thus, their win-set does not include a strategy of complete information at the second level, either. In order to prevent conflicts selective information about what is happening at the working group level has to be conveyed to the constituencies.

From the point of view of the constituencies, negotiators at the first level are often in collusion due to shared interests in helping fellow group members get the results of their negotiations ratified at the second level. And, often enough, the first-level negotiators are, in fact, quite interested in colluding in order to reinforce each other's standing among their respective constituents and increase their win-sets. The so-called solidarity of the experts is frequently criticized by management and may lead firms to avoid cooperation when they have reason to suspect such tendencies. Conversely, engineers often complain about management's "course of confrontation" [17] endangering collaborations viewed by the engineers as being very productive and efficient. Hence, firms involved in R & D collaborations must be prepared to live with the fact that successful R & D cooperation requires researchers to develop dual loyalties and to tolerate that the interorganizational groups, at least to a certain extent, act independently of the interests of their constituencies.

Against this background, we must assume that each successful R & D collaboration requires *specific constellations* of actors and interests that enable actors to reduce complexity and uncertainty and to stabilize trust at both levels of the game. Since our example is a case in which these highly contingent requirements were fulfilled, it offers us an opportunity to analyze which conditions might be necessary for successful R & D collaboration. Accordingly, nearly all actors involved portrayed this collaboration as a kind of "unique and fortunate event. Prior to this project, German producers of adhesives could not be motivated to cooperate."

Paradoxically, at the onset of the project, motivation to participate was based on the competitive interests of each individual firm. Bilateral collaboration between one of the biggest producers of adhesives and a large automobile manufacturer could mean market share losses for firms choosing to remain outside the collaboration. In order to keep pace with technological standards in the field, each firm had an individual interest in joining the project. Once the large adhesives producer's competitors had decided to take part in the project, all adhesives producers came under pressure to take part. In terms of Arthur's [4] and David's [15] well-known models, the collaboration project resulted from a "lock-in process". Once the constellation of the participants was established or "fixed" by this lock-in process and once the collaboration project was constituted on an interorganizational level in its own right, a complex interaction process was set in motion in which the participants had to find a *modus operandi* for collaboration.

Attaining a *modus operandi* for collaboration, however, required that members of the group at least gradually emancipate themselves from the competitive interests of their respective firms. But this was no easy task. In the early phase of the project the group's work fell far short of the goal initially formulated by the institutes and the BMFT. Originally conceived to conduct research for precompetitive objectives, the collaboration evolved in such a way that the project members behaved predominantly as representatives of their firms and *competed* for orders from the automobile manufacturer. According to this competitive definition of the project situation, the participants were most concerned that "a project of this size would make it easy to deceive willfully", "that shrewd partners would receive information about the work of the others" and that there was a "risk of informing the others about one's own solution."

Thus, the *modus operandi* the members of the project agreed upon was simply to declare that competition for orders from the automobile manufacturer was the principle of the group's work. Each member was to develop an adhesive on its own, the properties of which would be examined by one of the institutes, which would then inform the project members about its tests, revealing the specific characteristics of the products but keeping the formula details secret. At the beginning of the project this *modus operandi* was welcomed by the representatives of the automobile manufacturer, too, who attempted to use the project as an opportunity structure to place the producers under competitive pressure.

It is easy to see that the procedure chosen by the participants at the beginning of the project led to a kind of segmented division of labor and therefore did not differ much from a number of single, bilateral collaborative projects. The representatives of the adhesive-producing firms were competing for orders from the car manufacturers, yet they played a *zero-sum game* with clearly defined win-sets. Their strategy was defined to maximize gains or minimize losses among the individual firms. Thus, the dominating interest in preserving secrecy prevented cooperation.

The arrangement differed slightly but deci-

[17] This quotation and all those following it paraphrase statements by participants in the project as recorded in the interviews conducted by Susanne Lütz (translations by authors).

sively from a purely segmented structure because of the testing conducted by the institute on the adhesives delivered by group members. By testing the adhesives and giving accounts of their specific properties, the institute fulfilled the function of an *informational broker*, which gave a new turn to the project. Institute reports informed each project member about the "state of the art" of adhesive technology among the competing firms. Since a strategy of "willful deceit" was highly improbable in this context because the members of the project were competing for orders from the automobile manufacturer, a rather clear picture of the state of the art in the technology of adhesives emerged: None of the firms taking part in the project provided a product even approximately fulfilling the requirements of the automobile industry.

For the majority of project members, this information altered their situation fundamentally. In contrast to the situation before the institute issued its reports, the information that none of the participating firms possessed a marketable product now made it feasible to define the group's work as precompetitive. Furthermore, results from testing the adhesives made it clear that the knowledge difference among the members of the project was not as great as had been expected based upon the firms' varying market shares or the different size and equipment of the respective R & D departments.

While at the beginning of the collaboration the representatives of the small and medium-sized firms took it for granted that large corporations employed about 20 scientists and engineers to work on a project, the representatives of the large corporations expected the engineers from the smaller firms to be relatively unskilled and often incompetent. As the project continued, "both sides noticed that, in general, only two people are engaged in a project and that the quality of technical development depends on the qualifications of these employees". For many participants, this experience served to minimize differences in status among project members and facilitated defining the project situation as a community of equally qualified technical experts who could partially drop their roles as representatives of competing firms. Since differences in knowledge among the project members were nearly irrelevant, the danger of leakage was nearly irrelevant, too. In other words, the information about the state of the art in the technology of adhesives took the edge off the competitive situation in which the project members found themselves. However, this learning process alone would not have changed the direction of the project towards more collaboration. The representatives of the automobile manufacturer were also required to change their strategy, at least partially.

The automobile manufacturer's representative did, in fact, change their strategy. Paradoxically, their reason for doing so emerged as a result of their attempt to enforce competition among the producers. To intensify the race for the product best fitting their specifications, the representatives of the automobile manufacturer requested that during the second phase of the project, after the first phase, in which each producer had to develop an adhesive, only the products coming closest to the requirements be selected and optimized. Consequently, if a firm's product was not selected for the second phase of the project, the respective firm would be excluded from further competition.

The top management of the supplying firms adamantly resisted this request. For most of them, uncertainty about which group of products an adhesive would belong to in the end and the risk of investing in the development of an adhesive which could be excluded from optimization were too great. Almost all project members reported that during this conflict they had "immense problems" convincing their superiors to agree to further participation in the collaboration.

The pressure from management, which requested project participants to oppose the procedure proposed by the representatives of the automobile manufacturer, finally led to collective resistance. In "several meetings parallel to the project meetings" the so-called "adhesives group" decided to launch a "concerted action" and oppose the procedure requested by the automobile firm's representatives. Although the asymmetric relationship between the automobile corporation and its suppliers was never resolved within the project context, the conflict which resulted caused the automobile manufacturer's representatives to revise their definition of their interest in the collaboration. This reversal made it possible for the status differences between the representatives of the user and of the producers to be reduced somewhat. After being forced to yield to the producers' opposition to limiting the number of products to be optimized as well as to agree to cooperate with all producers during the entire project, the representatives of the automobile producer realized that they had "to pursue entirely different interests than in a bilateral form of cooperation". This meant that instead of insisting on "specific requirements for an adhesive with precise characteristics for a specific structural component" as they had before, the automobile manufacturer's representatives now attempted to use the collaboration project "to broadly consider technical developments which were of common interest and of an uncertain and problematic nature". Along with this change in the definition of interests, the focus shifted from the actual performance of automobile manufacturer's suppliers to their potential performance. From this new perspective on the purposes of the project, the automobile producer representatives could redefine their concept of collaboration: They encouraged the project group members to be less secretive and to develop a "give-and-take philosophy" among the project members. Not surprisingly, the automobile producer's representatives now emphasized "the precompetitive character of the group's work", too.

As a result of the project's revised objectives, the representatives of the user corporation also contributed to relieving the competitive situation of the suppliers, by presenting themselves as technical experts. This especially meant informing the other project members about their situation and the internal problems they needed to deal with as protagonists of the new production technology within the automobile corporation. In this way the project participants were informed that the representatives of the automobile corporation "had a great deal of trouble with adhesive technology", and were confronted with the difficult task of "making adhesive technology a popular alternative to welding".

As a matter of fact, within the automobile corporation "the idea of joining car-body parts with adhesives" was considered at that time to be "absolutely ridiculous". Adhesives were expected not only to reduce the quality of the car bodies but also to lead to problems in the production process which had been solved through enormous efforts in optimizing automated welding. Therefore, chances to rationalize the production of car bodies were not expected from a new technology but from the further development of automated welding by introducing laser technology.

Against the background of this information about the problems of introducing adhesives in the production of automobiles, the project situation could be interpreted now in new terms by all of the participants. Adhesive technology was far from being a mass-production technology. And if that was so, all participants in the project were worse off than expected. But being worse off collectively at the same time meant that the relative benefits of possible gains from cooperation, compared to the possible gains from competition, increased.

Resulting from this revised perception of the group's status quo, the situation of the suppliers, which was interpreted at the beginning as a zero-sum game, could be now transformed into a *positive-sum game*. This did not alter the interest of any representatives of the adhesive producers "to demonstrate the firm's technological competence" to the representatives of the automobile corporation. But considering this situation, in which adhesive technology still was far from being a mass-production technology, a successful demonstration of the competence on the part of a competitor did not necessarily reduce the market chances for the others. Demonstrating competence could generally help "strengthen the user's trust in adhesive technology" and thereby give credit to the whole adhesive industry. In this perspective, the individual interests of the suppliers could be combined with the collective interests of the industry to support the representatives of the automobile corporation in achieving their mission to introduce adhesive technology as a mass-production technology. Within the frame of a positive-sum game, the competitive relationship among the representatives of the supplying firms was re-interpreted in terms of "sportsmanlike competition". In contrast to the earlier situation, within this kind of competition an interest in the success of the whole team evolved, in addition to each firm's interest in its individual success.

In spite of the asymmetric relationship between the automobile corporation and its suppliers and in spite of conflicts among the representatives of the supplying firms, this new frame made it possible for the members of the project to develop "a common language between technical experts". Accordingly, distributive issues receded into the background. The project was now determined, first of all, to "prove the product's quality to be credible", whereas the decision "whether good project work turns into market shares depends on too many imponderables".

Legitimating this new perspective on the project within the firms, however, required "perseverance and persuasiveness". Convincing management of the project's new objectives required not only allaying its fears of losing know-how but also proving that the project was strongly oriented to market applications. But since there was a user in the project, there was little danger of losing contact with practical problems. The development of the adhesives was closely oriented to special applications in car-body design. For the project members, being willing to collaborate was not synonymous with ceasing to compete. Rather, the constellation of the actors competing within the frame of a positive-sum game balanced the situation: they were free enough to do creative work but remained under a certain pressure to keep their firm's interests in mind.

Accordingly, most of the participants in the collaboration project maintained the critical balance of neither showing too much collegiality nor purely pursuing the market interests of their firms. Within this double game, the cooperation among the project members became very informal. The exchange of formulas and data was defined as a "confidential matter between engineers". Thus, the formulas and data were not made accessible officially but were confidentially passed on in personal conversations. More and more, the project's function was to serve as an informal network of experts "with different knowledge in an open discussion of technical problems, without giving the whole show away". Informal exchange of information was regulated by a strict norm of reciprocity among the project members. Only those participants willing to pass on information received information.

Taking the different views of the participants into account, most of them agree in retrospect that scientific knowledge and technical know-how was widely enlarged by the collaboration. Some of the participants characterized the project as a "programme of continuing education". But the success story of this project told here should not be generalized too soon. The success of the project required a very specific constellation of actors and interests to solve the distributive problems and to define a positive-sum rather than a zero-sum situation. It was only after these problems were solved that the user–producer constellation made "sportsmanlike competition", i.e. a creative coexistence of competitive and cooperative interaction orientations, feasible.

6. Conclusion: A cascade model of industrial R & D collaboration

Using a case study in which companies and scientific institutes successfully cooperated within an R & D project as an example, this paper traces the complexities of networks in industrial R & D. It proposes a *cascade model* to describe a process in which, initially, a large number of technicians and researchers from industry and academia met in a loosely coupled network to discuss possible future developments in the adhesive sector and in which, at the end, a smaller group of researchers from a small number of companies and scientific institutes cooperated in a government-sponsored R & D project to successfully prove the applicability of adhesives in mass-production processes. Three stages are specified in the cascade model to analyze this process.

Stage 1: The establishment of a scientific-technical network

At this stage, a platform for the development of a community of experts in the field of adhesives was created, transforming a previously heterogeneous field of mostly unrelated actors into a dense communication network. Thereby, an infrastructure of cooperation was established which could be used by a large number of actors to interactively develop a shared vision of technological challenges in the sector and of technological paths expected to open up in the future. The activities of a highly qualified and motivated mobilizer were identified as being critical in the creation of a network, and the existence of scientific-technical and business associations in adjacent technological areas was shown to greatly facilitate the process of institutionalizing collective activities in the emerging field of adhesives.

Stage 2: Agreement on R & D collaboration

At this stage, a smaller number of companies and scientific institutes agreed to create a joint R & D project with the purpose of proving the applicability of adhesives in mass-production processes. A specific interest constellation of participating partners was found to be critical for the agreement. Most importantly, the participation of an attractive user made it possible for initially quite diverse individual interests among the participants, especially among competing companies from the adhesive sector, to be made compatible. In contrast to widespread expectations in the literature on R & D collaboration, questions of distributive justice among cooperating partners did not represent a major obstacle in the process of forming the joint R & D project. The primary purpose of the contract between partners in the project was to provide for workable exit options if a member found that the collaboration did not meet its expectations.

Stage 3: Collaboration within R & D projects

The activities that actually led to the aspired innovation took place at the level of a group of researchers representing their respective organizations. Serving as boundary spanners, these researchers at the laboratory level were engaged in demanding two-level games since they needed to establish a functioning intercompany research team and simultaneously keep their companies' interests in mind. Successful cooperation within the research group was found to presuppose that researchers were placing their joint R & D work in a precompetitive sphere and that they were able to develop interaction orientations which emphasized the common gains from cooperation, rather than distributive issues.

On the surface, the complexity of this model suggests that successful R & D cooperation among companies and research institutes, starting from scratch as it were, is rather unlikely. Not only are there difficulties and obstacles at every stage of the process, but the cascade model goes on to suggest that successful mastery of problems at early stages constitutes a precondition for promising attempts to master those at later stages.

On the other hand, it was also demonstrated that achievements at earlier stages greatly facilitated overcoming obstacles at subsequent stages. In abstract terms, the modular and historical character of the process of establishing successful R & D collaboration has been emphasized. In more concrete terms, past experiences of companies with joint projects or a long history of collaboration within industrial sectors would certainly facilitate the establishment of joint R & D projects among companies sharing these experiences. On another level, the existence of a great number of institutions acting to bring together researchers and technicians from various industrial sectors and scientific institutes could also be expected to foster successful R & D cooperation among firms. Such an institutional infrastructure may thus be considered an essential feature of successful sectoral, regional or national "systems of innovation".

Industrial R & D collaboration depends on a variety of institutional prerequisites rendering successful cooperation highly contingent. Thus, and in contrast to much of the management literature on R & D collaboration, the managements' ("top-down" or strategic) role in securing interfirm collaboration is rather limited. Instead of more or less prescriptive theories, we need a clearer empirical and analytical notion of the functionally essential features of institutional infrastructures that promote innovation.

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