Subtheme 1:
Path Dependence and Creation Processes in the Emergence of Markets, Technologies and Institutions

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Path-Creating Networks: The Role of Consortia in Processes of Path Extension and Creation

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ABSTRACT

The paper explores the role of interorganizational networks in the process of creating technological paths and tries to answer the question whether, and under which conditions, such paths can be mindfully be created. For that reason, six modes of constituting technological paths are distinguished, whereby path creation and path extension are two of the more reflexive modes of path constitution. Both are illustrated by investigating the organizational forms and practices of two R&D consortia in the semiconductor industry: SEMATECH and EUV LCC. First insights into the role of such consortia in processes of path extension and creation are presented.

FIRST DRAFT, COMMENTS WELCOME.

INTRODUCTION: PATH-CREATING NETWORKS AS A FORM OF ORGANISING INSTITUTIONAL ENTREPRENEURSHIP

Consortia are a prominent way of coordinating pre-competitive R&D activities today. However, what consortia do and how and to what extent they influence the development of even key technologies like semiconductors is not well understood. Understanding the impact of consortia on the process and path of technology development in the semiconductor industry would enable us to account for a basic aspect of performance of modern industrial societies for three interrelated reasons. First, all leading industrial nations often directly relate their abilities to cope with the challenges awaiting them in the near and mid-range future to the development of this industry. Second, technology development in semiconductors influences innovation processes in diverse industries, from the production of consumer goods to manufacturing technology to military weapon systems. Third, the development of innovation in this industry is often highly complex and costly so that, as a result, most efforts are being conducted not by a single actor, but collectives of actors. Sometimes this process is guided by the assumption that only one of a set of feasible options will be viable and, finally, survive.

This paper explores how collectively organised innovation processes in the semiconductor industry are shaped and to what extent collectives of actors, e.g. R&D consortia, can be considered to be path-creating networks in the sense that they actively promote one particular technological option. We draw on the notion of path creation coined by Garud and Karnøe (2001, 2003) while, at the same time, trying to locate path creation in a comprehensive typology of different forms of path constitution as well as specifying the process of organising networks for collective institutional entrepreneurship. Empirically, we look at the activities related to the major challenge for the semiconductor industry when it comes to producing ever smaller features on silicon chips. As generally known, the evolution of semiconductors is largely based on a prediction by Intel co-founder Gordon Moore, commonly referred to as Moore's Law, roughly stating that the number of transistors on a chip will double every two years. Unfortunately, the traditional way of making chips by exposing them to light (lithography) has gradually reached its physical limits, and to be able to continue meeting the demands of Moore's Law, the semiconductor industry has to look for new ways of making chips – commonly referred to as Next Generation Lithography (NGL). Whoever masters the technology to make very small structures at a comparatively low price will have a great advantage over his competitors. But since in NGL the technological challenges are so demanding and the financial burden is extremely large, no single player dares, if at all able, to make the switch from classical optical lithography to NGL by himself. A world-wide effort to introduce a feasible and affordable technology is currently underway, connecting semiconductor manufacturers, such as Intel, AMD, and Samsung, with tool suppliers such as ASML, with their respective contractors such as Zeiss SMT, with government agencies such as DARPA and, last but not least, with R&D consortia such as SEMATECH. The central thesis of this paper is that these (mainly corporate) actors organise for institutional entrepreneurship in complex inter-organisational networks that may become active as either path-creating or path-extending networks. The process of these organising activities is explored in some depth.

In this paper we especially focus on the role of R&D consortia in geographically distributed innovation processes and their ability to facilitate technological progress. In line with Garud et al. (2002), who build on DiMaggio's (1988: 14) insight that "[n]ew institutions arise when organised actors with sufficient resources *(institutional entrepreneurs)* see in them an opportunity to realise interests that they value highly", we think of technological innovation as a case of – increasingly collective – institutional entrepreneurship. For the creation and implementation of (new) technological knowledge is a socially complex and embedded phenomenon that increasingly requires: first, the collaboration of other individual and corporate actors, some of them even actual or potential competitors; second, the co-creation of markets and of other institutions, by influencing buyers' preferences, for example, or setting technological standards; and, sometimes, even the creation of completely new industries or "organizational fields" (DiMaggio and Powell 1983). In the field of NGL there are several technological options that were considered as promising successors to optical lithography, but so far none has been put in production and probably will not be for another couple of years. The R&D consortia mainly try to focus the efforts of the individual companies and also serve to distribute the risk in case of failure. As *networks* of companies, they provide a basis for pre-competitive knowledge exchange, actually linking competitors in a mutual innovation effort. Next to their achievements on the technological side, they may also provide a stage for the promotion of a specific option, favouring one over another. This understanding lies at the core of our idea of R&D consortia as an important part of path-creating networks.

The paper proceeds as follows. In the next section we conceptualise paths as very specific processes and develop the typology of path constitution. Then, taking the case of NGL as an example, we highlight the role of consortia in the processes of path creation and extension, and, in particular, look at what consortia actually do in these respects. We seek to investigate their role in collective institutional entrepreneurship and how consortia become path-creating or -extending networks. The paper concludes with a summary and a list of challenges for future effort in path dependency/creation research.

CONCEPTUALISING PATHS AND PATH PROCESSES

The classic model of path constitution was originally proposed by David (1985) and Arthur (1989) and then developed in evolutionary economic theory (Nelson and Winter 1982, Dosi 1982, Witt 1997). The common denominator is the rejection of the idea of an omniscient, a-historical actor as imagined in neo-classical economic theory. However, this evolutionary perspective de-emphasises the active role that actors might play in creating technological innovations. Especially in order to understand processes of change and development, the agency of actors - and the agency of collectives of actors in particular - deserves a closer look. This will allow us to understand whether path processes are created by actors or emerge behind their backs (Garud and Karnøe 2001). One example often cited to explain path dependency is the dominance of the VHS recording system over Betamax[1], and in this case even Arthur (1994: 2) himself includes "corporate manoeuvring" as a force to be reckoned with in the initial stages of the competition.

Therefore we shall try to extend the classic framework of emergent path processes in order to include mindful contributions of actors and collectives of actors into the generation and the extension of a technological path. In order to specify the role that actors might play in the constitution of a path, it is useful to distinguish between three stages of path development or "structuration" (Giddens 1984): *generation*, *continuation* and *termination*. In each of these phases, the contributions of actors can be mapped on a bipolar continuum between *mindfulness* and *emergence*, which makes our concept gradualistic. Path dependency, in the sense of increasing returns and momentum, is an indispensable attribute of all path processes, be they mindful or emergent. Following this understanding of path dependence, agents can strive to mindfully create path dependency. Microsoft's activities concerning the X-BOX can at least be read from this perspective: for instance, if the console is sold at a comparatively

[1] Even though there has been some disagreement over case (Cusumano et al. 1992, Liebowitz/Margolis 1995).

low price in order to speed up the distribution into customers' homes, increasing the demand for the corresponding games, which in turn increases the supply of those games followed by an increased demand for the console itself. Even though this is no guarantee for creating a path, companies are certainly aware of increasing returns and the advantage gained from monopolistic standardisation and they subsequently use this knowledge in strategic decisions. However, it is important to see that path processes are constituted by collective actors, their activities embedded in institutional settings like organizational fields and national societies which enable and constrain their doings at the same time. Let us now turn towards explicating a more precise terminology for analysing processes of embedded path constitution in the light of mindful and emergent structuration on the one hand and the three phases of path constitution: path generation, path continuation, and path termination on the other (see Fig. 1).

Dimension / Phases	*Emergent with respect to path* *(predominantly unintentionally produced)*	*Mindful with respect to path* *(predominantly mindfully produced)*
Path generation	path emergence	path creation
Path continuation	path persistence	path extension
Path termination	path dissolution	path deviation

Fig. 1: Phases and dimensions of path constitution: a preliminary typology

Path generation. In the approach taken by David and Arthur, a path comes into being by emerging behind the back of all parties concerned, pending on the self-reinforcing process of increasing returns. In this case, *path emergence* occurs in an unplanned and uncontrolled (maybe even uncontrollable) manner, and their final shape can only be explained by retrospectively tracing the historic events which lead to lock-in. Looking at mindful *path creation*, the focus switches to actors who pursue a certain goal and in the process of doing so also mobilise other actors to support their quest in a particular environment. As Garud and Karnøe (2001: 13-24) have shown in the case of the Post-it® Notes, an initial phase of undirected laboratory tinkering is followed by a deliberate and enduring campaign in the context of a firm once a certain technological possibility (there 'a glue that does not glue') has been turned into a potential product. Mindful processes by which a path is created have been analysed in a similar vein by many science and technology studies (Knorr 1979, Fleck 1980 [1935], Pinch and Bijker 1987, Latour 1988, Bowker and Star 1999) with a special emphasis on what has been called alignment (Latour 1987: 121) or closure (Bijker 1995: 84). In the processes of alignment and closure, alternative options are removed until only one solution prevails. In contrast to the understanding of path generation as emerging paths, however, the selection process is a highly political matter, laden with controversies, disputes and powerful actors, via strategic manoeuvring, seeking the implementation of the solution that they favour. In particular, the mobilisation of collectives of actors within or across an organizational field in order to lend momentum to the process deserves a closer look. Coming back to Garud and Karnøe, an additional question is whether the creation of a path is the consequence of mindful deviation from an existing path or a new path is established from scratch (as one could argue in the case of the typewriter: since there were no other typing machines before, and unless one considers the pencil to be just that). In the first case, actors have to be able to dis-embed from an existing path of technology development in order to re-embed an already existing technology into a new path; in the second case, no strong embeddedness related to a particular technology development needs to be overcome by the actors.

Path continuation. Nevertheless, once a path has been generated, whether by creation or emergence, a certain form of *irreversibility* must exist for the path to continue (Bassanini and Dosi 2001). David and Arthur call this phenomenon path dependency, stabilised by the mechanism of ever increasing returns and, eventually, leading into a lock-in. Again, it is the aim of their argument to explain the persistence of one technology in spite of the existence of superior technologies. So once the consumer has decided to use VHS instead of Betamax and the supply of pre-recorded tapes converges on the former system, it is neither financially wise nor convenient to stray from the established standard. The consumer market, especially in the case of technologies with high network externalities (Katz and Shapiro 1983), is a very good example showing how momentum builds up and is reinforced until a technological possibility is institutionalised as a standard. Because we consider these features of path dependency as essential elements of all path processes, we call the uncontrolled continuation of a path *path persistence*, with the self-reinforcing process of increasing returns as the motor for generating the necessary momentum to stick to the path. As we have shown in the case of path generation, in some cases these processes need not necessarily be beyond the control of actors. When entrepreneurial agency is essential to maintaining a path, we would like to call this kind of path continuation *path extension*, which can take the extreme form of path defending, when actors actively battle competing options, as in the case of German car manufacturers and diesel particle filters. Although there also has to be some sort of path dependency in the sense at least of increasing returns and of a definable momentum in path extension, we are interested in analysing the degree to which the proportions of path persistence and path extension might vary in specific cases. Consider for instance the physical shape of the Audio CD which has been extended to the shape of today's SACDs and DVDs and its successors like the Blue Ray Disk. Here, the consortia concerned with specifying the standards actively pursue 'downward compatibility', i.e. they are trying to make the future product fit into the existing landscape of available media. A technological disruption like in the transition from VHS to DVD can thus be evaded.

Path termination. In the whole literature on paths, little has been said concerning the possibility of path termination, mainly because the concept of paths is directed towards explaining stability and persistence rather than fragility and change. Nevertheless, to achieve a comprehensive view on path processes, one should consider the possible end of paths in addition to their generation and continuation. Following the proposed distinction of unintentionally produced, emerging vs. mindfully created path processes, one possible end to a path could be the unplanned *path dissolution*, when a path ceases to exist simply because no one uses it anymore (cf. Schreyögg et al. 2003). Thinking of technological devices, the once very common 3 ½ inch floppy disk has very much faded away from use with computers over the last 5 years, with no real successor to take its place (although there are now other portable devices such as rewritable CD-ROMs, USB sticks and memory cards). The second way to end a path is the mindful breaching of an existing path, which we call *path deviation*, best illustrated by Garud and Karnøe (2001) in their study of the invention of the Post-it® Notes. Another example would be the shift from analogue HiFi home entertainment, e.g. vinyl records and VHS videotapes, to digital equipment like Audio CDs and DVDs respectively.[2] Suppliers of the digital machines had to create a whole new market, tempt the customers to buy digital equipment and get, for instance, the music industry to discontinue the release of vinyl records. Such a step is of course a relatively large one and the deviation from an existing path may not be completely global, as in the case of laser disks, which was introduced in the late 1970s as a video playback device and never managed to move from the high-end market segment to the mainstream consumer market.

When a path comes to an end, the question of how the end came about is especially interesting if activities of collectives of actors are involved. As seen in the above examples,

[2] One could argue that using discs as information storing devices is a technological trajectory (Dosi 1982) and could be considered a path itself, but at this point we are especially concerned with the changes that occur when new products are introduced into a market.

the single player behind the laser disc (Pioneer) was not successful in replacing the VHS videotape. This deed was accomplished by the consortium that introduced the DVD.[3] The member companies include hardware producers as well as content providers and it is explicitly stated that the purpose of the consortium is “to encourage the broad acceptance of DVD Formats on a worldwide basis among members of the Forum, related industries and the public” (http://www.dvdforum.org). The analysis of embedded collective path deviation certainly promises interesting insights into the degree to which the agents are able to terminate an existing path while at the same time trying to create a new one.

In our understanding, a gradual concept of path processes is especially useful in order to take the agency (of individual and collective actors) into account, without having to dump the idea of path dependency altogether. As was said above, no matter how considerable the agency might be, there still need to be self-reinforcing processes at work in paths. Thus the question in all phases of path processes would have to be how much active intervention is exerted, to what extent this intervention is able to shape the path, and how and why actors are capable of mindfully shaping these processes. Consortia are highly interesting as one potential means to organise for creating and shaping, but also, as will be shown, for extending technological paths in contexts of modern capitalistic societies.

THE ROLE OF CONSORTIA IN PROCESSES OF PATH EXTENSION AND CREATION

Research and development in the semiconductor industry has long been a cooperatively organised activity. Many of the collective innovation efforts in this area are being pursued in R&D consortia, pooling technical expertise, coordinating financial investments and sharing risks between the consortia members. The best known example, and pivotal to the field of semiconductors, is SEMATECH (SEmiconductor MAnufacturing TECHnology), based in Austin, Texas. Before we go into the details of what SEMATECH is and actually does, we would like to specify the characteristics of consortia as an organisational form and the subsequent relevance for path generation, continuation and termination.

The term consortia is not well-defined as a specific organisational form and thus it is worthwhile to look at the general understanding of the term as well as the role of consortia in

[3] The initial partners being: Hitachi, JVC, Matsushita, Mitsubishi, Philips, Pioneer, Sony, Thomson, Time Warner, and Toshiba.

the semiconductor industry. Doz et al. (2000: 240) consider R&D consortia as a particular type of network, as “a legal entity established by two or more organisations that pool resources and share decision-making for cooperative research and development activities”. Hence, consortia constitute an *inter*-organisational network that – as a form of governance – enables actors to coordinate their activities, not least with respect to the generation, continuation and discontinuation of technological paths. At the same time, such a network is a result of these coordinative activities and – very much like technological paths – may be either dominantly ‘engineered’ or ‘emergent’ (Doz et al. 2000). R&D consortia in general and SEMATECH in particular have already been investigated with respect to network formation processes (e.g. Grindley et al. 1994; Browning et al. 1995; Doz et al. 2000). Though researching organisation for technological development, and in some cases even considering *paths* of network formation (Doz et al. 2000), these studies do not analyse these types of networks with regard to their potential to generate, continue or even discontinue technological paths. By contrast, studies of technological paths, at least to our knowledge, have not considered the networked characteristics of consortia in great detail.

Even in highly competitive industries, such as semiconductors, consortia and similar network-types of organisation offer a pre-competitive space for collaboration in research and even development (Browning et al. 1995). Moreover, they may be considered as an arena for negotiating technological standards. However, even the landmark studies on technological standard setting by Garud and colleagues (Garud et al. 2002; Garud and Karnøe 2001, 2003) and others (Brunsson/Jacobsson 2000) have not explored in detail the networked character of consortia as a medium and result of organising for creating or sustaining technological paths. In order to be able to do so, we first need a clearer understanding of what is meant by the term ‘consortium’ and of what makes consortia interesting from organisational and path-related perspectives.

Meaning and Relevance of Consortia

Although the notion of organisations forming a consortium is fairly common and applicable in most capitalist economies, there are also differences in the precise meaning of the term. For instance, corporate law in some countries such as Italy and Brazil defines the consortium as a distinct form of incorporation, while in other countries such as Germany consortia are treated legally simply as one empirical variant of a form of corporation governing temporary inter-firm cooperation. While in Europe, consortia are historically one of the oldest forms of business collaboration, in the United States, they were traditionally considered as violating anti-trust principles. R&D consortia, in particular, as a "new organisational form" (e.g. Evan and Olk 1990; Merrifield 1992; Avery and Smilor 1994) were only introduced in the United States in the 1980s: "R&D consortia have only existed officially in the US since 1984, when the NCRA [National Cooperative Research Act] was passed" (Aldrich and Sasaki 1995: 304).

Generally speaking, though, when an inter-organisational arrangement is called a 'consortium' by its participants or by outsiders, it means that the members of the consortium have a legally allowed agreement on jointly pursuing a particular purpose. Consortia are temporary in the sense that they are normally dissolved when the common project ends or the goal of the 'joint venture' is reached. Typically, to what extent resources are provided and leadership can be exercised by the members of a consortium are central elements of the more or less formal agreement underlying a consortium. Implicitly, and echoing the literal meaning of the term, consortia are set up among equals, i.e. horizontal cooperation or a very flat hierarchy within the project at least on the surface. (No member has any privilege unless this is part of the agreement.)

Moreover, organisations normally engage in consortia in addition to and parallel to their main business activities. In other words, although consortia may be strategically quite important, they do not represent the core of an organisation's ongoing business. Members do – in the cases we know of – not commit a very large proportion of their resources to a specific consortium as such and, overall, the level of dependence on individual consortia remains low. This said, many consortia are formed because the projects they undertake would be too large in terms of resources, skills and risks for any of their individual members to take on alone (see Child and Faulkner 1998). And some organisations, e.g. banks or construction companies, may be active in numerous consortia at any point in time and over time so that the proportion of business they generate through consortia may be quite substantial. Moreover, some consortia keep creating new projects so that they continue to exist (see for example the case studies by Corey 1997).

There is a point, though, at which the term 'consortium' is no longer appropriate and terms such as partnership, alliance or even business group would be more accurate. In Europe, *Airbus Industry* is a well-known case of an important aerospace consortium that was later transformed into a proper business group. In the United States, the term consortium is often associated with initiatives, notably by authorities or associations as well as private firms, towards ongoing pre-competitive co-ordination and R&D: “[R&D consortia] allow companies within and across industries to cooperate within one domain while competing in others” (Avery and Smilor 1990: 93). While such arrangements can certainly be seen as one type of consortium, at other times they also resemble industrial associations (e.g. Grindley et al. 1994: 724 with reference to SEMATECH) or collaborative partnerships that are called ‘consortia’ mainly in order to indicate that they lie outside of competitive markets. Overall, though, a consortium is considered to be a relatively loose, limited, low-involvement and low-dependence form of cooperation from the point of view of the individual participating organisations. At the same time, consortia may be of outstanding importance for the development of a new technology or even the transformation of a technological field and, hence, for all players involved in creating, shaping or transforming or simply participating in this field.

Interestingly, the relatively low level of commitment required from members individually on the one hand and the strategic importance for the field and its members on the other, could explain why this organisational arrangement is attractive – and particularly suitable – for reflexive path generation, continuation and also termination. First, in the face of high levels of uncertainty, consortia can spread the risk. Second, in consortia there is always an exit option. Third, this means that the entry barriers are relatively low so that, if desired, large numbers of members can be attracted. Fourth, once a sufficiently large number of participants have been enlisted, who provide a critical mass of resources in the aggregate, the self-sustaining mechanisms associated with the generation and continuation of a path can start to ‘work’. In other words, partly emergent and partly through reflexive shaping, consortia “generate momentum” (Garud and Karnøe 2001: 17) out of relatively small individual commitments by drawing them together and mobilising a collective investment in a path-in-creation with positive feedback. Through consortia – unless they grow too fast or too big – an alignment or at least boundary spanning between different interests and world views can be achieved which is required for collective entrepreneurship (see also Aldrich and Fiol 1994; Fligstein 1997). However, “consortia are difficult to manage” (Child and Faulkner 1998: 110) and therefore not a favourite option from a management control perspective. Avery and Smilor (1990) note three characteristics of consortia that make them difficult to manage: the interaction of multiple constituent cultures, simultaneous competition and cooperation, and the complex nature of the task (in particular, technology transfer). More broadly, Grindley et al. (1994) point out three challenges that explain the complexity of consortium design and management: definition of the research agenda and choice of projects; transfer of research results to participants; and adaptation to change in the economic and technological environment. Yet, this image of consortium as a "juggernaut" (Giddens 1990: 139) could be quite fitting for a path creation process (see Sydow et al. 2004: 5). And besides, some useful efforts at addressing the problems and possibilities of consortium management have already been made (e.g. Merrifield 1992; Aldrich and Sasaki 1995)

Types of R&D Consortia

With regard to technology development, but also in other areas, it is important to distinguish between different types of consortia according to the aims their members seek to achieve. Specifically, in pre-competitive consortia, common standards and basic research are pursued in order to create the conditions for later competition in applied R&D, product development and, eventually, sales to end users (Corey 1997).[4] This distinction already hints at another important aspect of consortia, namely their level and scope in a technological field. At one extreme, we can imagine a consortium that comprises all organisations in a given field and coordinates the formulation of a universal standard. At the other extreme, there could be a small consortium of two or three companies collaborating in a project that concerns merely a tiny facet of the overall knowledge and artefacts required on the way to a technological innovation.

A useful typology of R&D consortia, specifically, is introduced by Aldrich and Sasaki (1995: 307-314). They distinguish three dimensions by which to categorise R&D consortia. First, in terms of the *administrative arrangement*, the consortium may have "operating entities" or merely "coordinating committees". Second, the *research strategy* of a consortium may be focused or diffuse. And third, the *extent of government involvement* can range from no involvement at all to just contributing money to helping in the coordination of the consortium. Two further dimensions could be added: Fourth, consortia can have different expansion in time-space. They can be of short or, like SEMATECH, of a more enduring existence and they

[4] In contrast, consortia under competitive conditions do not create or co-create the market, as it were, but participate in the market when, for example, organisations collaborate in joint bidding or manufacturing for larger contracts, potentially against other consortia.

can be more locally or more globally oriented. Fifth, different consortia can be interrelated with each other to a varying degree in time-space, by shared membership or aligned activities, for example. What types of consortia are realized in reality is not least a reflection of the particular challenges and choices faced by their management when some of the issues highlighted above are more pressing than others.

Thus, very different consortia are to be expected empirically and there may be important connections between them in terms of multiple memberships of organisations and in terms of technological inter-relatedness. Hence, we need to be aware of the diversity of aims, levels, scopes and connections of consortia. This implies an increased complexity, especially when we take into account that relationships between consortia can take many forms, too: antagonistic vs. complementary, sequential vs. parallel, etc.

In the following section, we take these considerations into account and present the example of SEMATECH as a consortium that is justified in describing itself as “the world’s leading consortium” in the field of NGL, because it is by far the most influential and widest ranging inter-organisational arrangement and is responsible, for example, for a technology development road map which everybody in the field knows and refers to. However, we also describe more limited consortia such as the EUV LLC, which had one clear aim with regard to one particular stage of NGL development and ceased activity as soon as this aim was reached. We analyze both consortia with respect to the activities they undertake towards the constitution of NGL-paths and, thereby, possibly organize for a collective or even collaborative institutional entrepreneurship in the processes of technology development beside resting competitors in most other areas of activity.

SEMATECH AND EUV LCC: TWO R&D CONSORTIA IN THE FIELD OF NGL

The following section draws on different kinds of empirical data and methods. First, of course, there is the research already conducted in analysing consortia, especially SEMATECH (Grindley et al. 1994, Browning et al. 1995, Thorn 1995, Corey 1997, Ham et al. 1998, Browning and Shetler 2000, Linden et al. 2000, Carayannis and Alexander 2004). Second, we have conducted about 20 qualitative interviews with a broad range of actors in the NGL field so far. Third, we are analysing documents produced by the field, i.e. web pages, presentations and papers. And last but not least, we are visiting the relevant conferences and workshops. By combining all these methods and materials and analyzing them from a path constitution-as- structuration perspective, we are trying to trace the activities and events, the relevant players and the importance that the players ascribe to these activities and events. Thus, we aim for a combination of qualitative and quantitative analyses in order to capture the complex interrelations of companies, funding agencies, R&D consortia and technological innovation.

The multitude and variety of R&D consortia in the semiconductor industry signifies the demand for collectively reducing cost and sharing risk in developing and manufacturing computer chips. Already in the early 1970s, the US semiconductor supply industry pooled resources to lower production costs by creating a forum (the Semiconductor Equipment and Materials Institute - SEMI) in order to standardise, for instance, silicon wafers. Later on, other cooperative efforts were launched, like the SIA (Semiconductor Industry Association) in 1977 joining the forces of the main chip producers, which in turn funded the SCR (Semiconductor Research Corp) in order "to plan, direct and fund pre-competitive silicon research programs at major universities"[5]. All of these efforts were made due to external conditions: silicon shortage in the case of SEMI and increasing competition from Japanese IC manufacturers in the case of SIA and SRC.

SEMATECH

As noted above, the most prominent of all R&D consortia in the semiconductor industry is SEMATECH. Founded in 1987 by the SIA and SRC, including a connection to the U.S. suppliers to the semiconductor industry at SEMI called SEMI/SEMATECH (renamed Semiconductor Industry Suppliers Association – SISA in 1999), SEMATECH has been the key consortium in regaining and keeping the world leadership of the U.S. chip manufacturers. Its initial purpose was to provide liaisons for the suppliers and the manufacturers in order to strengthen the U.S. industry in the competition with Japanese manufacturers. In the first eight years, SEMATECH received about $ 200 million a year, contributed in equal proportions by the industry and government. The initial member companies included 14 U.S. semiconductor manufacturers (Intel, AMD, Motorola and IBM among them). A major driving force behind the founding of SEMATECH was the Defence Department, which considered foreign

[5] http://www.sia-online.org/abt_history.cfm (May 18, 2005)

domination of the U.S. chip industry a possible threat when it came to installing Japanese semiconductors in U.S. weapon systems (Ham et al. 1998). In the beginning, efforts to establish purely horizontal (among chip firms) or vertical (down to suppliers) cooperation failed; then a mix of both was created, minimising the risks for suppliers as well as manufacturers while offering advantages for both groups (Carayannis and Alexander 2004). Direct government funding for SEMATECH was stopped in 1996 when the U.S. were world market leader once again and the consortium made a move towards internationalisation. In 1998 a subsidiary called International SEMATECH was created to enable foreign companies (such as Philips, STM, Infineon or TSMC) to participate in SEMATECH activities. Finally, in 1999, International SEMATECH was dissolved and the non U.S. members were given full membership in SEMATECH, which in turn was renamed International SEMATECH in 2000 in recognition of its global membership base. Finally, International SEMATECH changed its name back to SEMATECH in September 2004, still being the leading global consortium: "SEMATECH is practically the worldwide leader, but does not make decisions on its own, since it has the international companies as members, except for the Japanese. … Intel and such companies decide what to do" (I09-11: 40).

Although government funding is still one of the most influential factors in R&D, likewise in the U.S., Japan and Europe, we will be focussing on the inter-organisational relations within the industry in the following sections, especially concerning SEMATECH's mission "to solve common manufacturing problems by leveraging resources and sharing risks"[6] and to be "the world's catalyst for accelerating the commercialisation of technology innovations into manufacturing solutions"[7]. The consortium has about 600 Employees, most of them being assignees from member companies, usually spending two years with SEMATECH.

SEMATECH Activities

Most of the visible activities that are being conducted can be described as simply *bringing people together* by organising workshops, conferences, the International Technology Roadmap for Semiconductors (ITRS) and last not least, the not so visible strengthening of personal ties between the assignees at SEMATECH itself. Thereby, the main focus is placed on the pre-competitive enabling of technologies and the coordination of research efforts by

[6] http://www.sematech.org/corporate/history.htm (May 13, 2005)
[7] http://www.sematech.org/corporate/ (May 17, 2005)

mutually anticipating future requirements. It is especially the extremely high investments and the dependence on many individual equipment suppliers that coerce competing manufacturers to join forces and try to control the complex R&D processes. In an Interview, SEMATECH's position with respect to R&D was described as follows: "SEMATECH is relatively strongly involved in the beginning of the (research) process, that is, it is mainly concerned with the infrastructures of such technologies. Before that, there is more science-orientated proof of concept studies, that is being conducted by SEMATECH or other industry partners with universities. ... While the development closer to production is later conducted in other consortia" (I16-15: 25).

In this respect, SEMATECH's activites, especially with respect to NGL, can be read from three perspectives. First, it funds a variety of different technological options, all of which are seen to have potential for future semiconductor manufacturing, i.e. sharing the risk and the cost in research. Second, it aims to identify the most promising technology and subsequently focuses funding in order to facilitate this option, i.e. levering the resources for development. Third, it absorbs at least some of the uncertainties connected to the research and development of new technologies. Within the supply chain necessary to support NGL, the chain is only as strong as its weakest link, for instance in the case of Extreme Ultraviolet Lithography (EUVL) – at this moment considered the most promising NGL option –, a failure on the side of the light source supplier would put all the other efforts at risk. It is this kind of information – and reaching common understanding – which is decisive for creating and/or extending a certain technological path.

Since success in the case of complex technologies like NGL does not depend on individual excellence, but rather on the collective competences of all parties concerned, a certain amount of mutual monitoring is exerted by all parties. The main locales for conducting mutual monitoring are conferences. For the semiconductor industry, the main event is the annual "SPIE International Symposium on Microlithography", hosted by the International Society for Optical Engineering in San Jose, California. This large event brings together all relevant actors in the community, where they present their own progress and evaluate the progress of the others. SEMATECH organises meetings on special issues alongside the conference, aiming more at the concentration of efforts on key problems than on presenting a broad platform for general encounters. In this way it satisfies the members' needs to integrate all the contributors of the supply chain in order to manufacture semiconductors, thus bridging the traditional gap between suppliers and manufacturers on an issue-based, problem-centred level. These workshops have been a central part of SEMATECH's work since the late 1980s, when they were used to identify the industry's needs in the first place (Carayannis and Alexander 2004). The focus shifted in the 1990s, when the pre-competitive work with the suppliers was viewed as a central aspect of making technological innovation happen. SEMATECH also links the industry with federal labs and universities through a number of Cooperative Research And Development Agreements (CRADAs), which were introduced after relaxing U.S. antitrust laws during the Reagan administration in order to support Government-University-Industry Strategic Partnerships (GUISPs). The CRADAs are usually realised under project management principles, ensuring a mutual benefit for both laboratories and industry (NASA 1998: 46) and can also serve as test stands, offering access to experimental technology for SEMATECH member companies. In addition SEMATECH maintains test centres of its own.

Both conferences/workshops and projects are centred around technological issues in the effort to pool resources, both intellectual and financial, and to provide locales for information exchange and reaching common understanding, but they are not instrumental for organising and steering the future development of semiconductor manufacturing; this is what the ITRS does. The roadmap serves to align R&D endeavours 15 years into the future and it "is a cooperative effort of the global industry manufacturers and suppliers, government organisations, consortia, and universities"[8], with SEMATECH as the global communication centre. Within the roadmap, Technology Working Groups are concerned with compiling the special areas of semiconductor R&D (e.g. front end processes, lithography, factory integration, etc.), thus building the roadmap itself. Even though the roadmap has a high reputation in the field, it should not only be seen as a technical instrument. From the interviews we have conducted so far it seems clear to all the actors that the roadmap is also a political arena, subject to manipulation in certain forms and is never taken at face value. To be on the roadmap means to have a certain amount of support for a technological option and can lead to more support in the future and as a general instrument for organising heterogeneous parties in a collective effort with equally high costs and risks, it is quite indispensable.

From a path perspective, SEMATECH's mission can be seen as being an institution to cultivate all sorts of prospectively promising technological paths, identifying the ones with

[8] http://public.itrs.net/ (18. May 2005)

more potential and supporting these until they have matured further. Again, SEMATECH's work is no guarantee for successfully generating a path, but it serves its purpose by building up momentum through conferences, workshops, projects and the roadmap. If SEMATECH decides to support an option it is a sign for other players to commit certain resources to this option as well, thus triggering the self-reinforcing process of increasing returns and absorbing some of the uncertainties connected to innovation. Of course the reverse is likewise true for the decision to abandon a technological path. Interestingly, increasing returns do not reside in the sphere of pure economic thoughts, but rather in the mutual evaluations of assessments concerning a technological path in order to obtain consensus. Increasing returns are a mix of technological estimations (is it physically possible?), social expectations (are my partners reliable?) and financial anticipations (what will the cost of ownership be?) and political negotiations (can we reach agreement?). In the field of NGL we find a complex arrangement of socio-techno-politico-economic relations bound together by consortia like SEMATECH. Since SEMATECH is more or less dispassionate concerning a specific path in the beginning, it is worthwhile looking at a consortium that actively tries to engage in the creation of a certain path.

EUV LLC

In the field of NGL, the EUV Limited Liability Company (EUV LLC) was such a consortium, committed to proving the feasibility of Extreme Ultraviolet Lithography (cf. Linden et al. 2000). As said above, EUVL is considered the most promising NGL technology today, but even though it is called a 'next generation', implying consistencies with traditional lithography, it is considered a 'big leap' with respect to many technological challenges. For instance, with EUVL, mirrors have to be used instead of lenses to focus the circuit pattern on a wafer, because EUV radiation is absorbed by the transparent material of the lenses. Also, it does not travel though air, so the whole process has to be conducted in a vacuum. Due to the short wavelength of EUV radiation (13.5 nm), the masks used to expose the patterns on the wafer have to be extremely defect free, because aberrations can hardly be compensated (for more information on the EUV path see Windeler 2003, Sydow et al. 2004). In addition, the question of how and when NGL will be in production is not only dependent on its own technical feasibility, but also on advancements in pushing the existing optical lithography to new, previously unimaginable, levels (Henderson 1995).

Nevertheless, in an unprecedented CRADA partnership initiated by Intel and the U.S. Department of Energy (Linden et al. 2000: 103), the EUV LLC set out in 1997 to prove the feasibility of EUVL[9] by constructing a prototype (ETS – Engineering Test Stand) at the national labs, which it successfully did in 2001. The founding members consisted of three manufacturers (Intel, AMD and Motorola) and three laboratories from U.S. Department of Energy (Lawrence Livermore National, Sandia National and E. O. Lawrence Berkeley National) with a three-year budget of $ 250 million, paid exclusively by the industry. Intel began pushing EUVL in 1996 and played a major role in establishing the EUV LLC.[10] The relation of the labs and the companies in the early days of NGL was described in an Interview as follows: "The EUV work was basically pushed by a number of national labs in the United States, in fact these national labs together with some U.S. companies, started the so called consortium EUV LLC, with the main purpose to build up some intellectual property on EUV technology." (I15-29: 12). This happened at a time when, once again, the limits of optical lithography were thought to be near and a promising successor was not at hand. In this respect, all interviewees have stressed the point that in semiconductor research they have constantly been working at the technological edge for the last fifteen years. Compared with the competing technologies, like Electron Projection Lithography (EPL) or E-Beam Direct Write (EBDW), EUVL was then and is still considered to be technically more challenging, but also more promising concerning throughput, making it more attractive for high volume production. As members in the consortium, EUV LLC brought together industrial IC manufacturers with government research facilities, thus spanning the boundaries between basic research and industrial production, with respect to a third party, namely the equipment manufacturers: "our goal is to make the equipment manufacturers as smart as possible"[11]. All of the people we have interviewed so far agreed that such cooperations are always built on necessity rather than want, since costs and risks are extremely high and a $250 million failure is too parlous for any single player. In case of developing EUVL, the heterogeneous partners teamed up for different reasons: the manufacturers felt they needed the new technology, but were afraid of the associated costs and risks and saw the CRADA as a way of tapping federal

[9] Roughly at the same time, efforts concerning EUVL were initiated by ASML in Europe with the EUCLIDES program and by the Japanese Ministry of International Trade and Industry with the ASET project.

[10] As Sander H. Wilson of Intel put it: "If this technology doesn't work, we're going to be out on the order of $250 million. On the other hand, if it works, what we want to do is recover our investment. But more importantly, what we want is access to the tools prior to our competitors who didn't take that risk." (cited in Linden et al. 2000: 103).

[11] Rick Stulen, chief operating officer at the government laboratories, quoted on http://fox.rollins.edu/~tlairson/ecom/Chips4.html (May 20, 2005). See also an Intel Press release at http://www.intel.com/pressroom/archive/releases/CN091197.htm (May 20, 2005).

funding. The national laboratories of course were happy to collect $ 250 million from the industry and the suppliers joined in, because they wanted to get the subsequent industry orders for the tools, once the proof-of-concept had been demonstrated. This form of collective action is typical of the recent technology developments in the computer chip industry. Manufacturers aim to exert control in basic research, first, because they want early experience with the technology and second, because the potential risk of a single component failing can jeopardise the whole endeavour.

EUV LLC Activities

During the course of research and development, the consortium and the technology co-evolved. On a larger level, this can be exemplified by looking at the member structure. After main problematic issues had been resolved in the first three years, two more manufacturers, Micron and Infineon, joined in, adding know-how and financial support, and a year later in 2001, IBM acceded, though they had favoured EPL until then. The EUV LLC commented that this move added further trust in the technology: "IBM's participation raises our confidence that EUV lithography will succeed both technically and commercially"[12]. This obviously shows increasing returns at work: the more promising a technology is, the more companies get involved, advancing the technology even further. In case of the EUV LLC, the companies' behaviour could be described as jumping the bandwagon (Fujimura 1988) for Micron and Infineon, whereas IBM was hedging its bets. Of course, the former two were also involved in alternative technologies, but were not pursuing them as much as IBM did EPL.[13] We can see that as the technology gains momentum by becoming ever more feasible, it attracts more parties on the broad level of membership in the consortium. On a more detailed level, the activities within the consortium change as the technology progresses. In the beginning, with many problems to solve, an open forum for discussing possible solutions is needed and free intellectual exchange in workshops is abundant. When moving from this pre-pre-competitive stage closer to production, the manufacturers become less revealing, in order to secure some sort of advantage over the consortium's members/competitors. The workshops then more likely serve the purpose of mutually monitoring the others' progress, although practical issues are still debated. An interviewee described it like this:"At the conferences

[12] http://www-03.ibm.com/chips/news/2001/0312_ibm-euv.html (May 20, 2005).
[13] This is a preliminary, yet educated guess from the interviews. Comments welcome.

there is still basic research being presented, by universities for instance, where you can learn something new. But when somebody from the industry says something, then he will at most tell you that they have solved problems or maybe that they have some problems, but they won't go into detail as soon as it is close to competition, so you won't learn how the problem was solved." (I17-40: 31).

With EUV LLC's activities linked to its technological progress, even after the official end of the consortium, it still is somewhat relevant for the development of EUVL, since it holds intellectual property in the form of over 180 patents or patent applications[14] and offers license agreements to suppliers. Again, the articulation of activities between universities, suppliers and manufacturers becomes visible. The consortium sought to speed-up and align basic research for purposes of the manufacturers, while at the same time providing an interface for the suppliers to participate in the process. This reciprocal aligning of interests does not come naturally, and especially on the side of the three government laboratories, initial interfering competition (with respect to funding) had to be overcome (Linden et al. 2000). Over time, the activities changed from pooling resources and sharing risks to organising collective institutional entrepreneurship with respect to the development of the technology.

Last but not least, it was the EUV LLC's purpose to prove the feasibility of EUVL and demonstrate this proof to the worldwide community of semiconductor suppliers and manufacturers, since "new technologies are always more expensive and drive to continue with what you have is strong" (I11-14: 52). In this sense, EUV LLC's activities were also concerned with making the progress visible and credible by issuing press releases or hosting events. Thus, the activities of this consortium, and this is also true in the case of SEMATECH, are not only directed towards the resource structures of the field, but also towards its rules of signification and legitimation (Giddens 1084).

Comparing SEMATECH and EUV LLC

In which ways are SEMATECH and EUV LLC similar and what makes them distinct? In terms of structure and duration the answer is quite obvious. Both consortia varied in membership over time, starting as pure U.S. enterprises and later taking on foreign companies, and while SEMATECH incorporates only manufacturers, EUV LLC was a mix of

[14] http://optics.org/articles/ole/7/3/2/1 (May 24, 2005).

industry and government (see Fig. 2). Both were in one way or another jointly funded by industry and government. Even though SEMATECH had succeeded in recapturing world leadership of the U.S. semiconductor industry in the mid 1990s, it continues to exist until today and has subsequently turned to other fields of interest, like NGL for instance. EUV LLC, on the other hand, only continued to exist for some more months after the engineering test stand was presented.

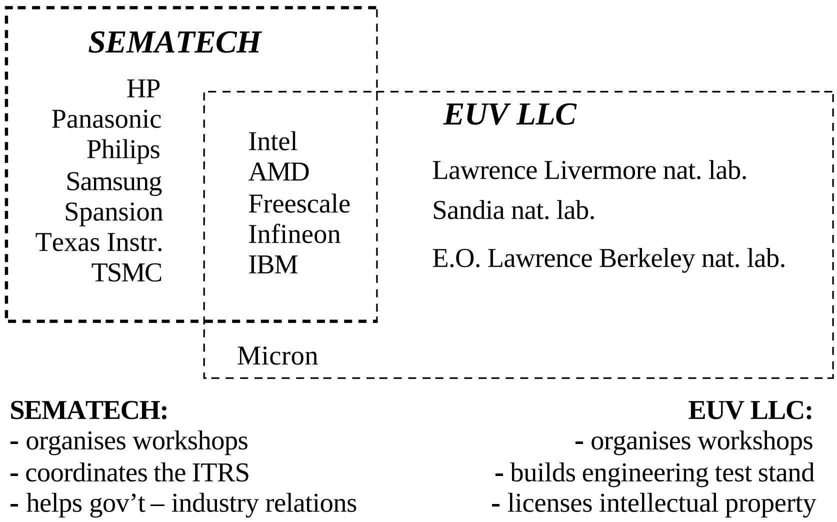

Fig. 2: Brief description of SEMATECH and EUV LLC

Needless to say, the activities of the consortia vary according to their mission. While SEMATECH now aims to provide a global platform for technology development (consider the ITRS for instance) and is more or less dispassionate with respect to any specific technological option, EUV LLC had the single purpose of pushing EUVL's readiness for production. In addition, it is important to note that the consortial activities are financially marginal in relation to the overall activities of the individual companies, often a few percent of total R&D investments, no matter how influential they might be concerning the development of a technology. Nevertheless, these activities are strategically extremely important, because they imply the possibility of generating, continuing and/or terminating a technological path. In all these three possible cases, R&D consortia like SEMATECH and EUV LLC are social locales for increased reflexivity in general and collective institutional entrepreneurship in particular, both leading to path creation rather than emergence, to path extension rather than simply persistence, and to path deviation rather than dissolution.

In terms of path creation, SEMATECH pursued widespread efforts in the field of NGL, owing to the diverse interests of the member companies, although a concentration on EUVL can be observed in recent years. By the same token, SEMATECH also seeks to extend the current lithographic technologies (with 193 nm immersion lithography) for the sake of prolonging the application of established solutions by enhancement technologies. For the specific case of NGL this means that manufacturers can stick to the traditional optical lithography path for some more time – again (c.f. Henderson 1995) – until they have to make the switch to a new path, which is currently still uncertain and will definitely be very expensive. Thereby, defending a path via path extension remains a viable option that has the advantage of avoiding sunk costs, not only with regard to technical equipment and human capital, but also to interorganisational relations.

EUV LLC, on the other hand, could be considered a role model for a path-creating network, since it set out to make one single path the most viable option by building a critical mass of interorganisational relationships. Since then and up to its dissolution, it attracted more and more parties in the process, increasing the returns and building up momentum, thus playing an essential part in EUVL now being considered the most promising option for next generation lithography.

SUMMARY AND CHALLENGES:
CAN TECHNOLOGICAL PATHS BE INTENTIONALLY CREATED AND EXTENDED?

Interorganisational networks in general and R&D consortia in particular are not only widely used in processes of technological development, they also seem to be useful in the process of creating technological paths, i.e. they are, at least potentially, path-creating networks. After such technological paths have been defined as processes that necessarily imply some degree of path dependency and, thus, may lead into a lock-in, path creation and path extension[15] were located as two among six possible types of path constitution processes. Together with path deviation, these two are more mindful types of path constitution processes. By contrast, path emergence, path persistence and path dissolution have been introduced as significantly less reflexive types of path generation, path continuation and path termination respectively. These,

[15] In the field of NGL, the latter is, at least at present, considered the only viable alternative the creation of a new path, i.e. EUVL.

however, and because of the economic and societal importance of the semiconductor technology, do not seem to be relevant in the field of NGL.

The empirical analysis of two R&D consortia that are involved in the process of creating a new and extending a present technological path, i.e. SEMATECH and EUV LCC respectively, has been conducted so far with respect to organizational form and organizational practices. With respect to *form*, it shows significant differences between these path-creating networks with respect to time-space extension. This is not surprising, given the different aims and scopes of the two consortia, and the different conditions of their founding. What is more important, and can also already be shown even in face of our still very limited data: the creation and/or extension of a technological path cannot simply be ascribed to a single R&D consortium, but has to be studied in the context of a broad range of relevant consortia and, possibly, other types of path-creating networks. From this, it follows that the empirical analysis would have to be broadened by including additional (types of) networks.

But in order to elaborate the path-creating potential of consortia as a form for organising collective institutional entrepreneurship, the analysis also has to be deepened. Though still at the beginning of our empirical investigation (and theory-based analysis of our empirical data) of coordinative *practices*, it seems to be clear that conferences, workshops, projects and road-mapping processes are decisive devices for putting (inter-) organizational form into (inter-) organisational practice, in this case for giving life to path creation and path extension. These activities, that have not been considered much in former studies of R&D consortia in the field of semiconductors (e.g. Browning et al. 1994, Browning and Shetler 2000), provide social locales and political arenas to exchange ideas, to reach common understandings, and to negotiate and renegotiate agreements. The same is true for the structure and quality of interorganisational relationships within and across such consortia. Together, practices and relationships do not only signify the diversity of forms of R&D consortia in the field but, together with the conditions of their founding, contribute to it recursively.

Detailing and expanding our empirical insights aside, it will be important to understand better when exactly a technological path emerges or has been created (or extended). Towards this end, it will be necessary to measure the 'degree' of path dependency involved in any path-in-the-making when it has stimulated positive feedback and gained momentum, no matter whether it is created, as in the case of EUVL, or extended as in the case of immersion lithography. Only then will it be possible to provide a definite answer to the question as to whether and to what extent technological paths can be created or extended/defended with the help of interorganisational networks.

REFERENCES

Aldrich, H.E./Fiol, C.M. (1994): Fools rush in? The institutional context of industry creation. In: Academy of Management Review 19 (4), 645-670.

Aldrich, H.E./Sasaki, T. (1995): R&D Consortia in the United States and Japan. In: Research Policy 24, 301-316.

Arthur, W.B. (1989): Competing Technologies, Increasing Returns, and Lock-In by Historical Events. In: Economic Journal, 99, 116-131.

Arthur, W.B. (1994): Increasing Returns and Path Dependence in the Economy. Ann Arbor: University of Michigan Press.

Avery, C.M./Smilor, R.W. (1990): Research Consortia: The Microelectronics and Computer Technology Corporation. In: Williams, F./Gibson, D.V. (eds.): Technology Transfer: A Communication Perspective. London: Sage, 93-108

Bassanini, A.P./Dosi, G. (2001): When and How Chance and Human Will Can Twist the Arms of Clio: An Essay on Path Dependence in a World of Irreversibilities. In: Garud, R./Karnøe, P. (Eds.): Path dependence and creation. Mahwah: Lawrence Erlbaum Associates, 41-68

Bijker, W.E. (1995): Of bicycles, bakelites, and bulbs. Toward a theory of sociotechnical change. Cambridge: MIT Press.

Bowker, G.C./Star, S.L. (1999): Sorting Things Out. Classification and its Consequences. Cambridge, MA: MIT.

Browning, L.D./Shetler, J.C. (2000): Sematech: Saving the U.S. Semiconductor Industry. College Station: Texas A&M University Press.

Browning, L.D./Beyer, J.M./Shelter, J.C. (1995): Building cooperation in a competitive industry: SEMATECH and the semiconductor industry. In: Academy of Management Journal 38, 113-151.

Brunsson, N./Jacobsson, B. (2000): A world of standards Oxford: Oxford University Press

Carayannis, E.G./Alexander, J. (2004): Strategy, Structure and Performance Issues of Pre-competitive R&D Consortia: Insights and Lessons Learned from SEMATECH. In: IEEE Transactions on Engineering Management, 51 (2), 226-232.

Child., J./Faulkner, D. (1998): Strategies of Co-operation. Oxford: Oxford University Press.

Corey, R.E. (1997): Technology fountainheads: The management challenge of R&D consortia. Boston, MA: Harvard Business School Press.

Cusumano, M.A./Mylonadis, Y./Rosenbloom, R.S. (1992): Strategic maneuvering and mass-market dynamics: The triumph of VHS over Beta. In: Business History Review, 66, 51-94.

David, P.A. (1985): Clio and the economics of QWERTY. In: American Economic Review, 75 (2), 332-337.

DiMaggio, P.J. (1988): Interest and agency in institutional theory. In: Zucker, L.G. (Ed.): Institutional patterns and organizations. Culture and environment. Cambridge, MA.: Ballinger, 3-22..

DiMaggio, P. J./Powell, W. W. (1983): The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. In: American Sociological Review 48, 147-160.

Dosi, G. (1982): Technological paradigms and technological trajectories. In: Research Policy, 11, 147-162.

Doz, Y./Olk, P.M./Ring, P.S. (2000): Formation processes of R&D consortia: Which path to take? Where does it lead? In: Strategic Management Journal 21, 239-266.

Evan, W.M./Olk, P. (1990): Consortia a new US organizational form. In: Sloan Management Review, 31 (2), 37-46.

Garud, R./Jain, S./Kumuraswamy, A. (2002): Institutional entrepreneurship in the sponsorship of common technological standards: The case of Sun Microsystems and Java. In: Academy of Management Journal, 45 (1), 196-214.

Fleck, L. [1935] (1980): Entstehung und Entwicklung einer wissenschaftlichen Tatsache. Frankfurt/M: Suhrkamp.

Fligstein, N. (1997): Social skill and institutional theory. In: American Behavioral Scientist, 40 (4), 397-405.

Friedberg, E. (1995): Ordnung und Macht. Frankfurt/M.: New York

Fujimura, J. (1988): The molecular biological bandwagon in cancer research: Where social worlds meet. In: Social Problems, 35, 3, S. 261-283.

Giddens, A. (1984): The constitution of society: Outline of a theory of structuration. Cambridge.

Garud, R./Karnøe, P. (2001): Path creation as a process of mindful deviation. In: Garud, R./Karnøe, P. (Eds.): Path dependence and creation. Mahwah: Lawrence Erlbaum Associates, 1-38.

Garud, R./Karnøe, P. (2003): Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship. In: Research Policy, 32 (2), 277-300.

Grindley, P./Mowery, D.C./Silverman, B. (1994): SEMATECH and collaborative research: Lessons in the design of high-technology consortia. In: Journal of Policy Analysis and Management 13 (4), 723-758.

Ham, R.M./Linden, G./Appleyard, M.M. (1998): The evolving role of semiconductor consortia in the United States and Japan. In: California Management Review, 40 (1), 137-163.

Henderson, R. (1995): Of life cycles real and imaginary: The unexpected long old age of optical lithography. In: Research Policy, 24 (4), 631-643.

Katz, M./Shaprio, C. (1985): Network externalities, competition, and compatibility. In: American Economic Review 75 (3), 424-440.

Knorr, K. (1979): Tinkering toward success: Prelude to a theory of scientific practice. In: Theory and Society, 8, 347-376.

Latour, B. (1987): Science in action. How to follow scientists and engineers through society. Cambridge: Harvard University Press.

Latour, B. (1988): The Pasteurization of France. Cambridge: Harvard University Press.

Liebowitz, S.J./Margolis, S.E. (1995): Path dependence, lock-on and history. In: Journal of Law, Economics and Organization, 11 (1), 205-226.

Linden, G./Mowery, D.C./Ham Ziedonis, R. (2000): National technology policy in global markets: Developing Next-Generation Lithography in the Semiconductor Industry. In: Business and Politics, 2 (2), 93-113.

Merrifield, B. (1992): Research consortia: The concurrent management of innovation. In: Haden, C.R./Brink, J.R. (eds.): Innovative models for university research. Amsterdam: North-Holland, 49-62.

NASA (1998): Communicating NASAS's knowledge. A report of the communicate knowledge process Team. National Aeronautics and Space Administration. http://www.hq.nasa.gov/ckreport/ck.pdf

Nelson, R.R./Winter, S.G. (1982): An evolutionary theory of economic change. Cambridge: Belknap Press.

Pinch, T.J./Bijker, W.E. (1987): The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other. In: Bijker, W.E./Hughes, T.P./Pinch, T.J. (Eds.): The Social construction of technological systems: new directions in the sociology and history of technology. Cambridge: MIT Press, 17-50.

Schreyögg, G./Sydow, J./Koch, J. (2003): Organisatorische Pfade – Von der Pfadabhängigkeit zur Pfadkreation? In: Schreyögg, G/Sydow, J. (Hg.): Managementforschung 13. Wiesbaden: Gabler-Verlag, 257-294.

Sydow, J./Windeler, A./Möllering, G. (2004): Path-creating networks in the field of Next Generation Lithography: Outline of a research project. Technology Studies Working Paper TUTS-WP-2-2004. Berlin: Technische Universität, Institut für Soziolgie. http://www.tu-berlin.de/~soziologie/Tuts/Wp/TUTS_WP_2_2004.pdf

Thorn, C. (1995): State involvement in the semiconductor industry: The role and importance of consortia. An examination of the Sematech and U.S. Memories projects. In: Willke, H./Krück, C.P./Thorn, C. (Eds.): Benevolent Conspiracies: The Role of Enabling Technologies in the Welfare of Nations. The Cases of SDI, SEMATECH, and EUREKA. Berlin: de Gruyter, 41-174.

Windeler, A. (2003): Kreation technologischer Pfade: ein strukturationstheoretischer Analyseansatz. In: Schreyögg, G./Sydow, J. (Hg.): Managementforschung 13. Wiesbaden: Gabler-Verlag, 295-328.

Witt, U. (1997): ‚Lock-ins' vs. ‚critical masses' – Industrial change under network externalities. International Journal of Industrial Organization, 15 (6), 753-773.