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Determinants of Evolutionary Change Processes in Innovation Networks – Empirical Evidence from the German Laser Industry

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Abstract

We seek to understand the relationship between network change determinants, network change processes at the micro level and structural consequences at the overall network level. Our conceptual framework considers three groups of determinants – organizational, relational and contextual. Selected factors within these groups are assumed to cause network change processes at the micro level – tie formations and tie terminations – and to shape the structural network configuration at the overall network level. We apply a unique longitudinal event history dataset based on the full population of 233 German laser source manufacturers and 570 publicly-funded cooperation projects to answer the following research question: What kind of exogenous or endogenous determinants affect a firm's propensity and timing to cooperate and enter the network? Estimation results from a non-parametric event history model indicate that young micro firms enter the network later than small-sized and large firms. An in-depth analysis of the size effects for medium-sized firms provides some unexpected yet quite interesting findings. The choice of cooperation type makes no significant difference for the firms' timing to enter the network. Finally, the analysis of contextual determinants shows that cluster membership can, but do not necessarily, affect a firm's timing to cooperate.

Keywords: network evolution, timing of network entry, innovation networks, German laser industry

JEL Classification: B52, D85, O32

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Determinanten des evolutorischen Wandels von Innovationsnetzwerken – Eine empirische Untersuchung am Beispiel der deutschen Laserindustrie

Zusammenfassung

Gegenstand der Studie sind interorganisationale Innovationsnetzwerke zwischen Laserstrahlquellen herstellenden Unternehmen und öffentlichen Forschungseinrichtungen. Das Ziel der Studie besteht darin, den Zusammenhang zwischen Determinanten der Netzwerkevolution, Evolutionsprozessen auf Mikroebene und daraus resultierenden Strukturveränderungen auf Ebene des Gesamtnetzwerkes vertiefend zu untersuchen. Unser konzeptioneller Bezugsrahmen umfasst drei Gruppen von Determinanten: organisationale (d. h. Eigenschaften der Unternehmen), relationale (d. h. die Beziehungen zwischen den Unternehmen betreffende) und kontextuelle (d. h. das Umfeld betreffende) Einflussfaktoren. Es wird davon ausgegangen, dass einige dieser Faktoren die Bildung und Auflösung von Kooperationsbeziehungen signifikant beeinflussen und somit eine Wirkung auf die strukturelle Evolution des Gesamtnetzwerkes ausüben. Unter Verwendung eines eigens zu diesem Zweck generierten Verlaufsdatensatzes, der 233 Laserstrahlquellenhersteller und 570 öffentlich geförderte Forschungs- und Entwicklungskooperationen umfasst, gilt es die folgende Forschungsfrage zu beantworten: Inwiefern beeinflussen endogene oder exogene Determinanten die Kooperationsneigung und damit den Netzwerkeintrittszeitpunkt der untersuchten Unternehmen? Die Ergebnisse einer nicht-parametrischen Verlaufsdatenanalyse zeigen, dass die Unternehmensgröße einen signifikaten Einfluss auf den Zeitpunkt der ersten Kooperationsbeziehung (Netzwerkeintritt) hat; mit zunehmender Unternehmensgröße verkürzt sich die Dauer zwischen Unternehmensgründung und Netzwerkeintritt, wobei Unternehmen mittlerer Größe eine Ausnahme bilden. Die Wahl der Kooperationsform (national vs. supranational geförderte F&E-Projekte) hat keinen signifikanten Einfluss auf den Netzwerkeintrittszeitpunkt. Schließlich zeigt die Analyse, dass der kontextuelle Faktor der Eingebundenheit in geographische Cluster den Netzwerkeintritt sowohl beschleunigen als auch hinauszögern kann.

Schlagwörter: Netzwerkevolution, Netzwerkeintritt, Innovationsnetzwerke, deutsche Laserindustrie

JEL-Klassifikation: B52, D85, O32

1 Introduction

Both economists and organization researchers agree that the evolutionary change of complex networks still represents a widely unexplored area of research (Parkhe et al. 2006, p. 562), (Brenner et al. 2011, p. 5). Quite recently scholars from various scientific disciplines such as physics (Barabasi & Albert 1999, Albert & Barabasi, 2002), biology (Nowak et al. 2010), sociology (Doreian & Stokman, 2005; Powell et al. 2005), organization & management science (Walker et al. 1997; Zaheer & Soda, 2009), economic geography (Glueckler, 2007) and economics (Jackson & Watts, 2002; Cowan et al. 2006) have started to intensify their research efforts in this area. Nonetheless, we still face more questions than answers.

The reasons for this are manifold. Firstly, network evolution is a complex phenomenon encompassing causes and consequences of network change among multiple levels of analysis. In the most basic sense, all types of networks consist of nodes and connections among these nodes (Wasserman & Faust, 1994). The concept of network evolution "[…] captures the idea of understanding change via some understood process […]" whereas these underlying processes can be defined as a "[…] series of events that create, sustain and dissolve […]" the network structure over time (Doreian & Stokman, 2005, pp. 3-5). Thus, network change processes at the micro level – i.e. tie formations or tie terminations – as well as changes with regard to network nodes – i.e. node entries or node exits – affect the structural configuration of networks over time. These processes of creative destruction are clearly Schumpeterian in nature and provide the basis to explain and understand the evolution of networks (Boschma & Frenken, 2010, p. 129). Research in this field is still in its inception. Secondly, micro level network change processes are determined by several factors which can be grouped into three categories: organizational, relational and contextual. Previous research has predominantly addressed only one of these categories. Surprisingly less research has been conducted on network formation processes affected by both endogenous and exogenous factors. Finally, even though tie terminations are as important as tie formations in understanding network evolution, there is a strong bias in the literature towards the presence of relationships compared to their absence (Kenis & Oerlmans, 2008, p. 299). This arises, on the one hand, from data availability issues as the majority of empirical studies are based on network databases in which tie terminations are systematically underrepresented (Schilling 2009). On the other hand we can observe in most studies a construct validity problem as tie failures and intended tie terminations are often not distinguished conceptually (Kenis & Oerlmans, 2008, p. 299).

Consequently, the aim of this study can be summarized as follows. On the one hand, an in-depth analysis of network change determinants requires a comprehensive understanding of network evolution in general. Thus, we propose a conceptual framework that consists of three building blocks: determinants, micro level network change processes and structural consequences. Starting from an evolutionary

Perspective (Hanusch & Pyka, 2007) we consider innovation networks as an integral part of an innovation system that can be both spatially and sectorally delimited (Cooke, 2001; Malerba, 2002). We apply an interdisciplinary approach to substantiate our framework by drawing upon concepts from evolutionary economics, sociology and organizational science. On the other hand, we derive and test a set of hypotheses that address some selected facets of evolutionary network change processes. More precisely, we raise the following research question: what are the endogenous or exogenous determinants affecting a firm's propensity and timing to cooperate for the first time and enter the industry's innovation network?

2 State of the art and theoretical background

2.1 What do we know about the dynamics of alliances and networks?

Several scholars have provided schemes to systematize the work in this field. In this paper we draw upon a general systematization scheme proposed by (VanDeVen & Poole, 1995) which has been applied and adapted to categorize dynamic oriented conceptualizations in the field of alliance (DeRond & Bouchiki, 2004) and network research (Parkhe et al. 2006) into three groups: life-cycle model, teleological approaches and evolutionary approaches.

The use of life-cycle analogies is not new to economics and has been employed to capture product exploitation stages (Levitt, 1965) as well as change patterns of industries (Klepper, 1997) or clusters (Menzel & Fornahl, 2009) over time. Life-cycle conceptualizations of alliance and network change are based on the notion of "[…] linear, irreversible and predictable progressions of events or states over time" (Parkhe et al. 2006, p. 562). The basic idea that underlies most of these models is that one can identify ideal development stages like initialization, growth, maturity and decline. Thus, some authors often refer to these models as phase models (Schwerk, 2000; Sydow, 2003). Change is imminent in life-cycle models which means that the developing entity has within it an underlying logic that regulates the process of change (VanDeVen & Poole, 1995, p. 515). The change process itself is regarded as a linear sequence of events where all development stages are traversed only once without disruptions or feed-back loops along the way. These events are cumulative in nature which means that each development stage in both alliance and network life-cycle models can be seen as a precursor of successive stages (VanDeVen & Poole, 1995, p. 515; DeRond & Bouchiki, 2004, p. 57).

Life-cycle or phase models are often found in the literature. For instance, Dwyer and colleagues (1987) have proposed a model of buyer-seller linkages in which relationships evolve through general phases: awareness, exploration, expansion, commitment and dissolution. A quite similar phase model has been presented for strategic alliances by Murray & Mahon (1993) by referring to five distinct stages: courtship, negotiation, start-up, maintenance, and ending. Other authors have proposed phase models that encompass four stages. For instance, Forrest & Martin (1992) suggest an alliance process model that consists of four distinct stages: matching, negotiating, agreement and implementation. The last category compromises three stage life-cycle models which are predominantly growth-oriented. For instance, Larson (1992) has proposed an entrepreneurial dyad formation model consisting of the stages: preconditions to exchange, conditions to build, integration & control. In contrast to this dyadic conceptualization Lorenzoni & Ornati (1988) introduced one of the first growth-oriented network formation models by arguing that firms that are expanding pass through three cooperation stages: unilateral relationships, reciprocal relationships and network constellations. Critics of life-cycle models have argued that the phase specification and the length of stages in these models may vary arbitrarily (Sydow, 2003, p. 332).

According to the teleological school of thought, change of organizational entities is explained by relying on a philosophical doctrine according to which the purpose or goal is the final cause of change (VanDeVen & Poole, 1995, p. 515). From this point of view development is regarded as a "[…] repetitive sequence of goal formulation, implementation, evaluation and modification of goals […]" whereas all of these sequences are affected by the experiences and intentions of an adaptive entity (VanDeVen & Poole, 1995, p. 516). This means that organizational entities are able to learn at each stage of the repetitive sequences and reformulate its goals. In response to the limitations of the previously discussed lifecycle conceptualizations, scholars have applied this teleological perspective in order to gain more open-ended and iterative process models of alliance and network change in which the final goal guides the underlying change process (DeRond & Bouchiki, 2004, p. 57). Teleological alliance and network change models do explicitly not refer to life cycle analogies. In summary, this view emphasizes "[…] purposeful cooperation by entities toward desired end states" (Parkhe et al. 2006, p. 562). As these models allow for learning and adaptation processes along all development stages, some authors refer to these models as non-linear process models (Schwerk, 2000; Sydow, 2003).

Most prominent applications of teleological ideas in an alliance and network context are non-linear process models operating on a dyadic level (Ring & VanDeVen, 1994; Doz 1996; Kumar & Nti, 1998; Arino & De La Torre, 1998). Non-linear process models provide a basis for analyzing dynamics but also the instability of dyadic alliances by considering endogenous factors like social embeddedness, trust, learning and knowledge transfer processes. In addition these models integrate the idea of feed-back loops. They consider forming and catalyst processes of alliances as well as a greater consideration of unplanned terminations meaning there is no fixed assumption with regard to phase transition patterns (Schwerk, 2000, p. 230). One prominent example of a non-linear process model was proposed by Ring & VanDeVen (1994). This model seeks to explain how and why interorganizational relationships emerge, evolve and dissolve. It considers three basis processes (negotiation, commitment and realization) and refers to the idea that formal and informal aspects need to be balanced in every process. The model proposed by Doz (1996) includes several internal and external dimensions – environment, task, process skills and goals – which are assumed to affect the processes of alliance change. The change process itself is characterized by sequences of interactive learning processes, reevaluation and readjustment. It allows for the explanation of both the successful development of alliances as well as the alliance failure (DeRond & Bouchiki, 2004, p. 57).

In the next step, research delved further into network process models (Sydow, 2003, p. 336). This approach has been strongly influenced by the contributions of the IMP research group (Hakansson & Johanson, 1988; Hakansson & Snehota, 1995; Halinen et al. 1999) and focuses predominantly on business relation networks. In these models network change is driven by market access and internationalization goals. For instance, Halinen and colleagues (1999) have proposed a dynamic network model that includes radical and incremental change processes at the dyadic and network level. The framework integrates the ideas of mechanisms, nature and forces of change and contains two interdependent circles of radical and incremental change which are affected by external drivers of change and stability. In summary, the strength of teleological alliance and network change models lies in the rejection of simplistic, uniform and predictable sequences of change towards more realistic non-linear process models which recognize that unplanned events, unexpected results, as well as conflicting interpretations and interests can and do affect the change process (DeRond & Bouchiki, 2004, p. 58).

Evolutionary conceptualizations of alliance and network change draw our attention to "[…] change and development in terms of recurrent, cumulative, and problematic sequences of variation, selection and retention." (Parkhe et al. 2006, p. 562). Evolutionary approaches seek to understand the forces that cause network change (Doreian & Stokman, 2005, p. 5) which means that the underlying determinants and mechanisms of network change processes move into the foreground. Evolutionary conceptualizations can be grouped into three categories: network emergence, network evolution and co-evolutionary approaches.

The first category – so-called network emergence approach – focuses on determinants and mechanisms affecting alliance formations and associated network change patterns at the overall network level (Walker, et al. 1997; Gulati, 1995; Gulati & Gargiulo, 1999; Hagedoorn, 2006; Kenis & Knoke, 2002). These growth oriented models consider both endogenous as well as exogenous factors of alliance and network change and recognize the importance of previous network structures in current cooperation decisions (Gulati & Gargiulo, 1999). However, there is clearly little consideration placed in these studies on tie termination processes and the associated structural consequences for the overall network configuration. In response to these limitations, network evolution explicitly encompasses both network formation processes as well as network fragmentation processes by considering simultaneously the determinants and mechanisms behind these processes (Venkatraman & Lee, 2004; Powell et al. 2005; Amburgey & Al-Laham, 2005; Doreian & Stokman, 2005; Glueckler, 2007). The main point of network evolution models is to understand why and how networks emerge, solidify and dissolve over time. For instance, Powell & colleagues (2005) have analysed the underlying mechanisms such as "cumulative advantage", "homophily", "following the trend" and "multi-connectivity" in order to explain the structural evolution of complex networks in the US-biotech industry. Organizational scholars have analysed the impact of tie formations and tie terminations on the component structure and connectivity of networks (Amburgey & Al-Laham, 2005). Economic geographers have argued that evolutionary processes of retention and variation in network structure are affected by a spatial dimension (Glueckler, 2007). Co-evolutionary approaches concentrate on simultaneous change processes between networks and other subjects of change such as industries (Ter Wal & Boschma, 2011), technologies (Rosenkopf & Tushman, 1998) or even other types of networks between the same actors (Amburgey et al. 2008).

2.2 An evolutionary view on organizational and interorganizational change

Despite the differences among evolutionary schools of thought, one can identify some cornerstones that create the common ground for evolutionary thinking in economics and related disciplines (Witt, 2008; Aldrich & Ruef, 2006; Amburgey & Singh, 2005; Dopfer, 2005; Stokman & Doreian, 2005). Firstly, the preceding discussion reveals that evolutionary theories generally focus on dynamic change rather than on analyzing static or comparative static snap-shots of economic activity. Closely related to the first point is that evolutionary theories agree on the notion of path dependencies and irreversibilities, in other words, that past and present events affect the current decisions and behavior of economic actors (Arthur, 1989; David, 1985). Thirdly, the idea that change occurs simultaneously across multiple levels of analysis is common to most evolutionary approaches. For instance, organizational ecology scholars have analyzed intraorganizational evolution, organizational evolution, population evolution and institutional evolution (Amburgey & Rao, 1996). Economists have proposed a differentiation between three levels of analysis: "micro", "meso" and "macro" (Dopfer et al. 2004). Thus, the majority of evolutionary theories are in line with the notion that change occurs simultaneously and interdependently across multiple levels (Amburgey & Singh, 2005, p. 327). Finally, evolutionary theories explicitly include the underling mechanisms, drivers of rules that guide the change process. In general, most evolutionary scholars would agree on the idea that evolution includes an understanding of the forces that initiates or drives change (Doreian & Stokman, 2005) and mechanisms of modification or replacement of existing entities (Amburgey & Singh, 2005). Glueckler (2007) explicitly proposed the application of general evolutionary principles of selection, retention and variation on relationships in networks. In the following we concentrate on the Neo-Schumpeterian school of thought.

Neo-Schumpeterian economics has its intellectual roots in evolutionary economics, industry life-cycle theory, complexity theory and systems theory and incorporates the ideas of path dependencies, irreversibilities, bounded rationality and collective innovation processes among heterogeneous actors (Hanusch & Pyka, 2007).

Research in this field is centered on the role of knowledge and innovation for development and economic prosperity of firms and societies. Witt (2008, p. 555) identifies the following topics at the core of the Neo-Schumpeterian research agenda: innovation, R&D, firm routines, industrial dynamics, competition, growth and the institutional basis for innovations. Hanusch & Pyka (2007, pp. 276-277) argue that the focus on novelty and uncertainty provides the most distinguishing mark of Neo-Schumpeterian economics and incorporate three constitutive normative principles: qualitative change affects all levels of economy; idea of punctuated equilibria encompassing smooth as well as radical change; and change processes characterized by non-linearities and feed-back effects responsible for structural pattern formation and spontaneous structuring.

The Neo-Schumpeterian approach regards generation of novelty as a collective process of interacting heterogeneous economic actors (Pyka 2002). Networks allow firms to share knowledge, learn from each other and innovate (Pyka 2002; Hanusch & Pyka 2007). In addition, networks are not static, they change over time. New relationships are established and existing relationships may be adjusted or even dissolved depending on the needs, capabilities and cooperation strategies of the actors involved. Due to the very nature of these underlying processes, networks have to be regarded as complex evolving socio-economy systems.

3 Conceptual framework and hypotheses

3.1 General principles of network evolution models

Stockman & Doreian (2005, pp. 244-251) recommend five general principles for the construction of network evolution models. Firstly, the instrumental character of networks provides the starting point for modelling network evolution which means that the motives or goals of the actors involved have to be considered at the very beginning. Innovation research has identified a broad variety of motives for firms to participate in innovation networks (Pyka, 2002) whereas the exchange of knowledge and mutual learning can be regarded as the most salient for the collective generation of novelty among multiple actors. Secondly, in order to gain an in-depth understanding of the actors' actions and the structural consequences of those actions it is appropriate to assume that a network actor possesses only partial or limited local information. This means that network actors possess global knowledge in the rarest cases. Instead, Stockman & Doreian (2005, p. 245) argue that network actors should be seen and modelled as adaptive entities that learn through experience and imitation. This principle is consistent with the Neo-Schumpeterian notion of bounded rational agents with incomplete knowledge bases and capabilities (Pyka, 2002). The third principle highlights the importance of the relational dimension of cooperation. This means that the parallel tracking of goals by network actors affects the emergence of ties in a sense that both entities have to agree upon common goals and parallelize decisions. From an innovation network perspective this principle highlights the importance of integrating concepts that operate primarily on the dyadic level such as mutual trust or tensions between partners. The fourth basic principle refers to the complexity of evolutionary processes in networks. Stockman & Doreian (2005, p. 247) recommend designing network evolution models that are as simple as possible. The fifth principle refers to the falsifiability of network evolution models. The authors suggest that network evolution models should have sufficient empirical reference and conclude that "Statistical models are strongly preferred, as they enable the estimation of essential parameters and test the goodness of fit of the model" (Stokman & Doreian, 2005, p. 249).

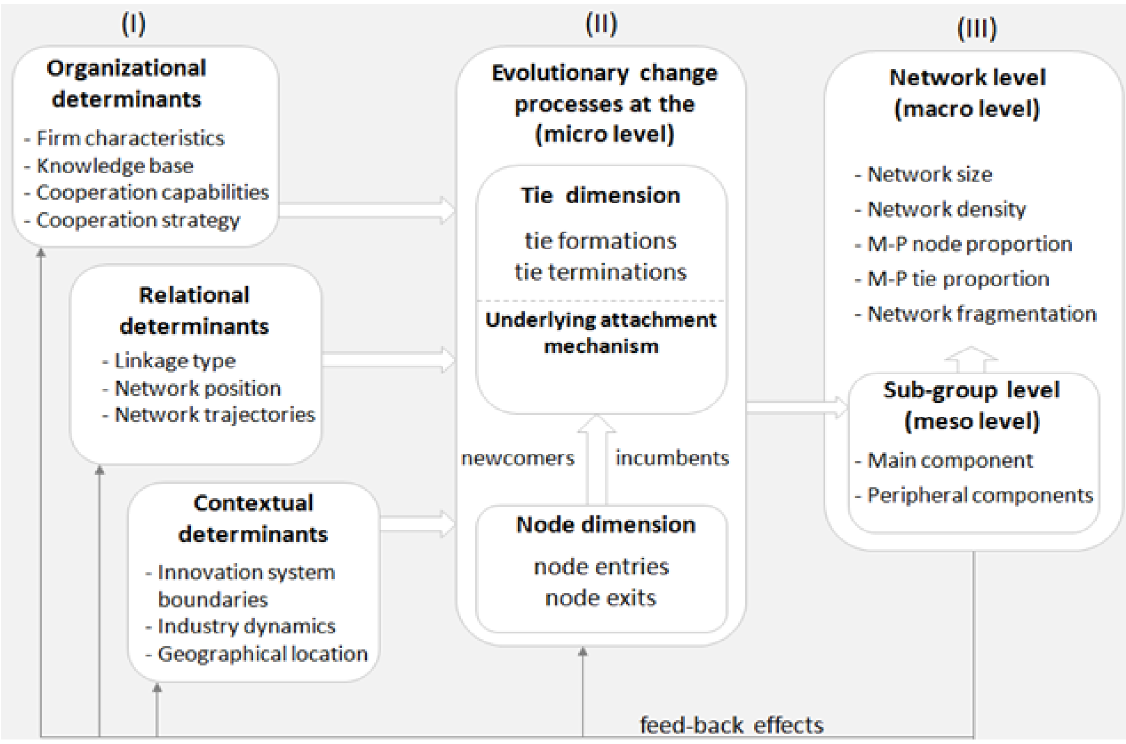
3.2 Elementary building-blocks of the framework

Network evolution is neither random nor determined (Glueckler, 2007, p. 620). This means that mechanisms have to be considered that create cumulative causation and lead to path-dependence as well as those mechanisms that produce contingency in a sense that the agent's strategies and actions may deviate from existing development paths resulting in path destruction (ibid.). In line with Doreian and Stockman (2005, p. 5) we regard the designations "network dynamics" or "network development" as more general terms to describe change of networks through time. In contrast, network evolution "[…] has a stricter meaning that captures the idea of understanding change via some understood process […]" whereas these underlying processes can be defined as a "[…] series of events that create, sustain and dissolve […]" the network structure over time (Doreian & Stokman, 2005, pp. 3-5). In addition, we have to note "[…] that the unit of analysis is always dyadic tie formation, whereas the object of knowledge is network structure" (Glueckler, 2007, p. 622). Based on the ideas outlined above we specify three elementary building-blocks in our conceptual framework (cf. Figure 1): (I) determinants of network change (II) micro level network change processes, and (III) structural consequences over multiple levels

Due to their very nature determinants that affect evolutionary micro level network change processes can be categorized as organizational, relational and contextual. To start with, we turn our attention on contextual determinants (cf. Figure 1, left). Firms and organizations in interorganizational networks are considered to be an integral part of a spatial-sectoral innovation system (Cooke, 2001; Malerba, 2002). Innovation systems have several characterizing features. Firstly, they consist of heterogeneous economic actors that are dispersed throughout geographical space within the system boundaries. Secondly, population of actors in the system can change over time which means that, for instance, firms or other types of organizations can, over time, enter the system (i.e. new founding, spin-off etc.) and exit the system (i.e. closing, failures, bankruptcies etc.). Thirdly, the systems elements do not exist in isolation; they are interconnected by various types of formal or informal linkages.

This leads to relational determinants in our framework. Dyads consist of at least one directed or undirected tie connecting two nodes in a well defined population and, at the same time, constitute the most basic building block of a network (Wasserman & Faust, 1994). Triadic components are more complex network building blocks (ibid). We refer to all components with more than two nodes as multi-node component. In this paper we specify innovation networks as formal, knowledge-related and publicly funded R&D partnerships among a well-defined population of firms and public research organizations. The existence of a tie among two nodes in innovation networks implies a certain degree of partner fit, mutual trust, cooperation capabilities and commitment to common goals between both parties (Gulati 2007). The sum of these dyadic network ties spans the overall innovation network within the system boundaries. Firms and organizations occupy qualitatively different positions within the overall network structure. These network positions are the result of cooperation decisions taking place in the shadow of the past (Gulati & Gargiulo, 1999). Doreian (2008) refers to this issue by introducing the concept of "network trajectories" in the context of evolutionary change process of networks.

Figure 1:
Network evolution – a conceptual framework



Source: Authors' own illustration.

Finally, we move on to organizational determinants in our framework. As we will establish in more detail later, firm characteristics such as size, age, origin, knowledge stock and cooperation capabilities etc. are likely to affect knowledge-related cooperation behaviour in innovation networks.

3.3 Evolutionary micro level network change processes at the core of the model

We continue the debate by moving on to micro level network change processes at the core of the model (cf. Figure 1, center). Glueckler (2007, p. 623) argues that "[…] a complete theory of network evolution […] has to theorize both the emergence and disappearance of ties and nodes".

To start with, we turn our attention on the node dimension. In the most basic sense we can differentiate between system actors who participate and who do not participate in a particular network. The first group encompasses all actively cooperating network actors, whereas the second group provides a pool of potentially available network actors. We follow the suggestion of Guimera et al. (2005) and differentiate between two groups of potential network actors: "incumbents" and "newcomers". Both groups are subject to change due to dynamics at the industry level. Entries and exits affecting actors within the first group (i.e. active network actors) have direct consequences for the structural configuration of the network, whereas the same events affecting actors in the second group (i.e. potential network actors) have an indirect impact by enlarging or reducing the pool of cooperation partners that are potentially available. To control for this node-related dimension of change in the German laser industry innovation network, one needs to have an exact picture of all laser source manufacturers (LSMs) and laser-related public research organizations (PROs) over time. We choose yearly time slots to capture the firm entries and exits at the industry level.

Now we will take a closer look at the tie dimension by considering two types of events – tie formations and tie terminations – to explain the structural change of the network. In line with Hite (2008) we refer to these events in the following as micro level network change processes. Moreover, tie formation and tie termination processes can be coupled or uncoupled. For reasons of simplicity, this paper focuses on coupled events. This approach has two considerable advantages. Firstly, we have an exact time tracking of all tie termination events which are, from a structural point of view, as important as tie formation events. Secondly, we considerably reduce complexity as tie termination processes do not follow their own underlying logic. We argue, in accordance with Nelson & Winter (2002) and in reference to Glueckler (2007), that micro level network change processes can be explained by the general evolutionary mechanisms of variation, selection and retention. At the same time, the formation and termination of partnerships are affected by the previously discussed determinants and follow the logic of underlying network change mechanisms. The preferential attachment concept provides one of the most frequently discussed tie formation mechanisms in network studies. The underlying logic is quite simple: highly connected nodes are more likely to connect to new nodes than sparsely connected nodes (Albert & Barabasi, 2002). Several other mechanisms and underlying logics of network formation processes have been discussed in the literature.

3.4 Structural consequences of evolutionary micro level processes

Only a few previous studies have analyzed the structural consequences of micro level network change processes (Elfring & Hulsink, 2007; Baum et al. 2003; Amburgey & Al-Laham, 2005). Our framework draws upon an evolutionary ideas and network change models proposed by Amburgey et al. (2008), Guimera et al. (2005) and Glueckler (2007).

To start with, we take a look at the model proposed by Amburgey et al. (2008). The authors provide a conclusive theoretical explanation for structural consequences of tie formations and tie terminations by introducing four distinct structural processes: (a) the creation of a bridge between components, (b) the creation of a new component, (c) the creation of a pendant to an existing component and (d) the creation of an additional intra-component tie (Amburgey et al. 2008, pp. 184-186). The framework provides us with very valuable insights. Nonetheless, these considerations have to be extended and refined in several ways.

Firstly, we argue that tie formations and tie terminations, as well as subsequent structural consequences, depend on the actor's strategic orientation. Strategies and actions of network actors can result in the destruction of existing network paths (Glueckler, 2007, p. 620) and they determine, at the same time, the scope of future cooperation options and possibilities. Thus, we propose and integrate three basic types of knowledge-related cooperation strategies into our framework: progressive, moderate and conservative. Progressive strategies are characterized by a firm's objective of considerably improving its knowledge base by accessing multiple knowledge sources simultaneously or by establishing and controlling global knowledge streams that connect entire groups of actors in the networks. The underlying objective of moderate strategies is to gradually improve the knowledge base through linkages to a few selected individual partners or through the establishment and control of local knowledge streams. Conservative strategies aim to secure a firm's knowledge base by protecting the existing knowledge stock or by securing and sustaining existing local or global knowledge channels.

Secondly, the framework of (Amburgey et al. 2008, pp. 184-186) primarily focuses on the tie dimension and neglects the importance of different types of actors for the structural evolution of networks. As outlined above, not all actors are involved in a particular type of innovation network. Instead, a considerable number of system actors are not embedded at all whereas others cooperate repeatedly with same partners. To account for this fact we follow the suggestion of Guimera et al. (2005, p. 698) and split the population into “newcomers” and “incumbents”. This gives us four distinct partnership constellations: “newcomer-newcomer” (NN), “incumbent-newcomer” (IN), “incumbent-incumbent” (II) and “repeated incumbent-incumbent” (RI).

Thirdly, under real world conditions we can frequently observe the formation and termination of both dyadic ties connecting two actors but also of large scale multi-partner projects that encompass a large number of actors. Consequently, we explicitly differentiate between dyadic and multi-node components in our framework. Finally, in the majority of real world networks the main component usually fills more than 90% of the entire network (Newman, 2010, p. 235). This substantiates the assumption that essential elements of industry-specific technological knowledge are tied into the main component. In contrast, peripheral components are likely to entail only small rather specific fragments of the industry’s technological knowledge. Thus, we argue that there is a qualitative difference between whether network change processes affect the core or the periphery of the network. Figure 2 (on the left) summarizes our foregoing considerations and illustrates at the same time the anticipated structural consequences at the overall network level (Figure 2, right).

Figure 2:
Partner constellations, cooperation strategies and structural consequences

Partner types	Cooperation options		Knowledge-related cooperation strategies			Structural consequences				
			progressive	moderate	conservative	Size	Density	Fragmentation	M-P node proportion	M-P tie proportion
N	NN	N1			*No cooperation*	/	/	/	/	/
		N2		*New dyadic component*		⇧	/	⇧	⇩	/
		N3	*New multi-node component*			⬆	/	⬆	⬇	/
	NI	N4			*No extension*	/	/	/	/	/
		N5		*P component extension*		⇧	/	/	⇩	/
		N6	*M component extension*			⇧	/	/	⇧	/
I	II	I1			*M-comp. fragmentation*	/	⇩	⇧	⇩	/
		I2		*P component consolidation*		/	⇧	/	/	⇩
		I3	*M component consolidation*			/	⇧	/	/	⇧
		I4			*P-P component merger (dyad)*	/	⇧	⇩	⇩	/
		I5		*P-P component merger*		/	⇧	⬇	⬇	/
		I6	*M-P component merger*			/	⇧	⬇	⬆	/
	RI	I7	*Network solidification*			/	⇧	/	/	/
		I8		*Network fragmentation*		/	⬆	/	/	/

Legend:

N = Newcomer
I = Incumbent

NN = Newcomer-Newcomer
NI = Newcomer-Incumbent
II = Incumbent-Incumbent
RI = Repeated Incumbent-Incumbent

M = Main component
P = Peripheral component

⬆⬇ pronounced structural effect
⇩⇧ moderate structural effect
/ no structural effect

Source: Authors’ own illustration.

To address the structural consequences at the network level we take look at newcomers who have two possible partner constellations (NN & NI) and six cooperation options (N1-N6).

We start our discussion on structural consequences by focusing on the moderate knowledge-related cooperation strategy of newcomers. Actors aiming to gradually improve their knowledge base through selected individual collaborations basically have two options: either they can cooperate with another potential newcomer which would lead to the creation of a new dyadic component (N2) or they can connect with an incumbent who is embedded in a peripheral component (N5). The structural consequences are consistent with the structural processes b) and c) identified by Amburgey et al. (2008). However, we have to consider two additional knowledge-related cooperation strategies. Conservatively oriented actors who predominantly aim to protect their existing knowledge stock are likely to isolate themselves from other newcomers or incumbents. Thus, neither is a new component created (N1) nor an existing component extended (N4). In both cases, the structural configuration of the network is not affected. Even though these two cooperation strategies have no direct structural consequences they are important in understanding what prevents potential network entrants from cooperating for the first time. In contrast, progressively oriented actors seek to improve their knowledge stock considerably by accessing multiple diverse knowledge bases simultaneously. The initialization of multi-partner projects among newcomers (N3) leads, from a structural perspective, to the creation of a multi-node component. In contrast, the establishment of a linkage to an incumbent in the main component of the network offers a broad variety of direct and indirect knowledge-accessing opportunities (N6) and is reflected in the extension of the main component.

The structural consequences for the cooperation options (N2) and (N3) are quite similar but less pronounced in the first case. The creation of new ties affects the number and size distribution of components (Amburgey et al. 2008, p. 186). This leads to increasing network fragmentation and a decreasing proportion of nodes in the main component in relation to nodes in peripheral components. A look at the cooperation options (N5) and (N6) reveals that the number of components remains constant but the network size is affected. This is in line with structural implications anticipated by Amburgey et al. (2008, p. 186). However a closer look at the proportion of nodes in the main and peripheral components reveals two opposing structural effects for the cooperation options (N5) and (N6). Moderate cooperation strategies produce a situation in which the main component shrinks in relation to the network's periphery. On the other hand progressive strategies lead to a relative growth of the main component compared to the network periphery.

Now we turn our attention to incumbents who, like the newcomer, have two possible partner constellations (II & RI). In this context, Amburgey at al. (2008, p. 186) differentiate between two structural processes: the creation of a bridge between two components and the creation of intra-component ties. This distinction provides valuable insights into the structural consequences of cooperation events between previously unconnected or indirectly connected network actors (I1 - I6). However, in order to refine the picture we have to separate consolidation processes from solidification and fragmentation tendencies in the network. Thus, we explicitly consider the structural consequences of repeated ties between already connected incumbents (I7-I8). Moreover, we account for path dependencies in our framework. By referring to (Glueckler, 2007, p. 620) we argue that the initial cooperation strategy of a network entrant affects its later cooperation path. In other words, the initial cooperation event is hereditary in a sense that it does restrict cooperation opportunities, yet at the same time, it opens up new cooperation opportunities. Below, we refer to this very specific type of network path dependence as “cooperation imprinting”.

Figure (2) illustrates six potentially achievable cooperation options (I1-I6) among previously unconnected incumbents (II). Newcomers who have pursued a moderate network entry strategy start the next cooperation round out of a dyadic component located in the periphery of the network. In contrast, the situation looks quite different for newcomers who have a progressive strategic orientation at the onset. These actors started their cooperation path by creating a new multi-node component and linking themselves to the main component. In both cases the conditions at the onset of the next cooperation round are considerably better than for network entrants with a moderate strategy.

The previous considerations imply that incumbents who are located in the network periphery and are still pursuing a moderate cooperation strategy are likely to look for cooperation opportunities in their direct neighbourhood. This case addresses the creation of alternative knowledge channels in peripheral components (I2). In contract, we can think of peripheral incumbents who change their strategic orientation towards a more progressively oriented cooperation behaviour. These actors actively search for novel knowledge stocks and tend to establish or control knowledge streams to other groups of network actors. This case is reflected, from a structural perspective, in the emergence of brokerage ties among peripheral incumbents (I5). In summary, we can observe the consolidation of a connected peripheral sub-graph on the one hand, and the amalgamation of two previously unconnected, peripheral sub-graphs on the other. Both structural processes are in line with the model proposed by Amburgey et al. (2008). However, it is important to note that the cooperation options (I2) and (I5) in our framework exclusively address structural consequences that occur in the periphery of the network due to the network entrants’ cooperation imprinting.

Now we look at incumbents who entered the network by pursuing a progressive cooperation strategy (using N3 or N6). Network entrants who linked themselves to the main component (using N6) face quite a comfortable situation in the next cooperation round. On the one hand, they can expand their position in the main component by establishing direct links to new partners in the main component (I3) or they can wait for new specific knowledge accessing opportunities to pop up in the network periphery in order to establish bridging ties (I6). However, main component actors can also pursue a conservative strategy in order to protect and secure the existing knowledge stock. In other words, a main component actor can decide to withdraw from the main component by leaving the main component either alone or together with a handful of strategic partners. The structural consequences are far-reaching, especially in the latter case (I1). The overall network density decreases, the fragmentation of the network increases and the component shrinks in relation to the periphery.

Actors with a progressive cooperation imprinting and who entered the network through the creation of a new multi-node network component (using N3) start the second cooperation round from the network periphery. However, multi-partner projects provide a better starting point than dyadic components because they are much more visible and prestigious. Incumbents with a progressive strategy can establish a bridging tie to an actor in the main component (I6). This strategy provides access to essential elements of an industry-specific technological knowledge pool tied into the main component and leads to an amalgamation of a peripheral component with the main component. Incumbents pursuing a moderate cooperation strategy will try to gain access to the much more specific knowledge pool by bridging the gap to another peripheral multi-node component (I5) or, in case of a conservative cooperation strategy, to another dyadic component (I4).

A comparison of options I2 & I3 reveals some interesting structural implications. In both cases the network density is affected. This is in line with structural implications anticipated by Amburgey et al. (2008, p. 186). At the same time the ratio of main-component ties to peripheral-component ties reveals an opposing structural effect. The amalgamation of two previously unconnected network components affects the density and fragmentation of the network (Amburgey et al. 2008, p. 186). Furthermore, the differentiation between main and peripheral components (I5 & I6) once again shows an opposing structural effect.

Finally, we take a look at repeated incumbent-incumbent partnerships. Repeated partnerships can occur sequentially (at different points in time) or parallel (at the same points in time). Not only the former but also the latter case is quite important but frequently neglected in network evolution studies. We refer to these ties as redundant network ties. These ties secure access to external knowledge sources on the one hand, while providing the opportunity to exchange qualitatively different stocks of knowledge among the same partners. In addition, redundant ties have far-ranging implications for the overall network structure. We argue that redundant ties can affect the stability of the network in several ways. Basically we can distinguish two cases: the previously outlined ideas substantiate the argument that a network in which progressive and moderate cooperation strategies dominate is likely to show a solidification tendency (I7). In contrast, a network in which moderate and conservative cooperation strategies dominate is likely to show fragmentation tendencies over time (I8).

3.5 Hypotheses development

Based on our previously introduced framework we now derive a set of hypotheses that addresses only a few selected facets of the entire evolutionary network change process described above.

The resource-based view (Wernerfelt, 1984; Barney, 1991; Peteraf, 1993) suggests that a firm's ability to achieve and maintain a profitable market position and outperform competitors depends, to a large extent, on its ability exploit both internal resources (Barney, 1991) as well as external resources (Gulati, 2007) and generate a competitive advantage. In this context, it has been argued that small firms face some substantial disadvantages compared to larger firms in the form of limited reputational, human capital and financial resources (Lu & Beamish, 2006). Small firms can overcome their resource constraints and counteract their comparably high risk of failure – also known as "liability of smallness" (Barron et al. 1994) – by forming alliances with external partners (Baum et al. 2000). Proponents of the knowledge-based view have argued that alliances allow firms to gain access to external knowledge stocks (Grant & Baden-Fuller, 2004) and learn from cooperation partners (Hamel, 1991) in order to gain competitive advantages (Dierickx & Cool, 1989; Coff, 2003) and resist the increasing pressure of global competition.

However, given the need and willingness of these firms to cooperate, there are several factors that are likely to hamper their ability to cooperate for the first time or which delay network entry. Firstly, in the pre-cooperation phase it can be quite difficult to assess a potential partner's intentions (Dacin et al. 1997, p. 7). This enhances the level of uncertainty, especially in international alliances (ibid.). Secondly, potential network entrants have to make considerable effort and spend both time and limited resources on identifying potential cooperation partners (Dacin et al. 1997, p. 4). From a new institutional economics perspective we would argue that a firm faces considerable screening costs to overcome information asymmetries and lower the adverse selection risk (Ackerlof, 1970; Spence, 1976). These search costs, however, are likely to cause a disproportional burden on small firms due to their comparably low resource endowment in the pre-cooperation phase. Once potential partners are identified, other obstacles are likely to delay network entry. Small firms lack alliance management capabilities (Schilke & Goerzen, 2010) and standardized cooperation interfaces (Goerzen, 2005). Finally, Lu & Beamish (2006) point to the fact that SMEs are usually owned and managed by the founders and decision-making is much more centralized compared to larger firms. This, however, is likely to delay the responsiveness of decision makers at lower hierarchy levels and may hamper the firm's ability to react rapidly to newly emerging cooperation opportunities. Thus, we formulate our first hypothesis:

H1: Smaller firms need more time to enter the network than larger firms.

With regard to relational determinants the question arises as how the type of cooperation impacts the time it takes a firm to initialize its first cooperation event. During the past decades substantial efforts were undertaken by both the EU and by the German government to support key industries. The funding of R&D cooperation projects is regarded as a key policy instrument. The main difference between these two cooperation types is that EU-framework projects explicitly aim to encourage scientific and technological cooperation between member states whereas national funding initiatives predominantly aim to address domestic applicants. There are some clear benefits associated with international R&D project environments. According to Gunasekaran (1997, p. 639) these include access to new and different technologies, enhanced scope of potentially accessible technological knowledge stocks, better access to qualified employees and a broad range of training opportunities for technical personnel. Nonetheless, there are also some difficulties that go hand in hand with international R&D projects. The pre-formation phase is characterized by higher search costs to identify potential partners. In the post-formation phase, international alliances require greater investments in communication and transportation to support interaction among the partners involved (Lavie & Miller, 2008, p. 625). Project governance costs tend to be higher due to a higher level of uncertainty (ibid.). In addition, it is well recognized that cross-national cultural differences may affect interaction between firms and organizations in multiple ways (Hofstede, 2001). Firms entering cross-national cooperation projects face the challenge of adjusting to both a foreign country and to an alien corporate culture (Barkema, et al. 1996, p. 154; Lavie & Miller, 2008, p. 626). Differences in national culture are reflected in differing managerial ideologies of decision makers and have the potential to significantly affect strategic decisions in both the pre and post alliance formation phase (Dacin et al. 1997, p. 6). As a consequence, it has been argued that cross-national cultural differences are likely to affect a firm's attitude towards cooperation and thus the predisposition to enter international R&D consortia (Nakamura et al. 1997, p. 155). These considerations underpin our second hypothesis:

> **H2:** Firms can shorten the time it takes to enter the network by making use of national network entry modes.

Finally, we take a closer look at the contextual dimension. Based upon a proximity framework originally proposed by Boschma (2005) it has been argued by Boschma & Frenken (2010) that network change is likely to be affected by other dimensions of proximity such as cognitive, organizational, institutional or geographical proximity. Like other science driven industries (Owen-Smith et al. 2002) the German laser industry shows a pronounced tendency to cluster geographically (Kudic et al. 2011). Consequently, we focus here on the relationship between geographical proximity and a firm's cooperation timing. More precisely, we distinguish between inside-cluster and outside-cluster firms and analyse to what extent cluster membership affects the cooperation timing. First of all it is important to note that cluster membership does not require or imply network membership. Firms can be located in a densely crowded region without having formal partnerships to other firms or organizations in their immediate geographical surrounding. Theoretically there are three potential ways as to how cluster membership can affect a firm's propensity and timing to cooperate.

Firstly, it has been argued that the local environment generates positive externalities in terms of knowledge spillovers (Feldman 1999; Audretsch & Feldman, 1996). Social interactions between employees and decision makers within a regional agglomeration are an important information source. As a consequence, firms located in densely crowded industrial regions are made aware of local cooperation opportunities earlier than others. Thus, it is plausible to assume that regional environments can speed up a firm's search for potential partners and shorten the time needed to enter the network. Secondly, geographical proximity can also be accompanied by negative effects. Boschma (2005, p. 70) argues that highly specialized regions can become too inward looking and sensibilizes for problem of spatial lock-in effects due to a lack of openness to the outside world. This can result in a situation in which firms tend to favour old and well-established knowledge channels and do not see the necessity to initialize new formal partnerships with other firms or organizations. Or to put it differently, firms located in closed geographical environments are likely to have lower cooperation propensities and cooperate later than other firms. Finally, we can think of a situation in which cluster membership has no significant effect on a firm's propensity and timing to cooperate. It has been argued that a lack of geographical proximity can be substituted by other dimensions of proximity like, for instance, cognitive proximity (Boschma & Frenken, 2010). This would imply that outside-cluster firms can compensate for geographical disadvantages through other proximity dimensions. In a similar vein, one could argue that an inside-cluster firm's tendency to cooperate is not primarily affected by their regional surroundings but rather by other dimensions of proximity. To exemplify this point, far-distant firms working on similar problems and using the same technologies are more likely to establish a link than direct geographical neighbors with entirely different technology portfolios. Consequently, we formulate our last set of hypotheses:

H3: A firm's geographical surrounding can affect its timing to enter the industry network in one of the following three ways:

a: Firms located in densely clustered regions cooperate later than other firms

b: Firms located in densely clustered regions cooperate earlier than other firms

c: There is no significant difference between inside-cluster and outside-cluster firms with regard to their timing in entering the network.

4 Industry, data and methods

4.1 Introducing the German laser industry

There are a number of salient arguments that advocate using data from the German laser industry for conducting this study. Firstly, laser technology requires knowledge from various academic disciplines, such as physics, optics and electrical engineering (Fritsch & Medrano, 2010). It can clearly be characterized as a science-driven industry (Grupp, 2000) in which a firm's ability to innovate is a key factor in its performance and success. The interdisciplinary and science-based character of the industry is reflected in the high level of cooperation activities between German LSMs among themselves and with laser-related PROs (Kudic et al. 2011). Secondly, the economic potential of the industry has since become well recognized by national and supra-national political authorities. Over the past few decades, Germany has developed into a world market leader in many fields of laser technology. Mayer (2004) reports that 40% of all laser beam sources purchased worldwide in 2003 were produced by German LSMs. Last but not least, the majority of contemporary empirical studies on the evolution of networks are based upon data from the biotech industry. Findings, however, can differ significantly due to inter-industry differences in terms of the industry's technological maturity, firm size distribution or industry life cycle stages. Thus, an in-depth analysis of causes and consequences of micro-level network change processes based on data from other science-driven industries is clearly underrepresented but urgently needed.

4.2 Data and methods

Industry data came from a proprietary dataset containing detailed information on firm entries and exits for the entire population of German LSMs between 1969 and 2005 (Buenstorf, 2007). The initial industry data-set has been modified in several ways. Additional data sources were employed to gather supplemental information on firm entries and exits after 2005: annually published laser industry business directories (i.e. "Europäischer Laser Markt") provided by the B-Quadrat Publishing Company; data from Germany's official company register (i.e. "Bundesanzeiger"); industry data from the MARKUS database, provided by Bureau van Dijk Publishing; and industry data from the Creditreform archival database, provided by the Creditreform Company. We selected the firm or business-unit level for the purpose of this study. Corporate level entities were decomposed and broken down into the business functions or market segments they serve. We included predecessors of currently existing firms in our sample. Additionally, all changes in firm names and legal status were considered to ensure the full traceability of a firm's origin and development path. Firm exits due to insolvencies, mergers or acquisitions, and several modes of population entries were treated separately. We ended up with an industry dataset encompassing 233 German LSMs over the entire observation period between 1990 and 2010. To analyse the transition from the origin state ("no-cooperation") to the destination state ("first cooperation") we had to build up an event history dataset and account for all firms with "incomplete" cooperation histories to avoid left truncation and left censoring problems (Blossfeld & Rohwer, 2002, pp. 39-41). In cases where the number of censored observation units is small it is acceptable to simply exclude them (Allison, 1984, p. 11). Starting with the full population of 233 LSMs in our sample we identified 39 firms which were founded before 1990 and excluded them from the dataset. Thus, a total of 194 firms were potentially at risk for establishing their first cooperation event. Out of this population we ended up with a total of 112 cooperating firms whose first cooperation event unambiguously fell between 1990 and 2010.

Organizational level data was taken from basically the same raw data sources that were used at the industry level. Moreover, we used annually compiled count data on different types of laser related organizations – laser source manufacturers (LSMs), laser-related public research organizations (PROs) & laser system providers (LSPs) – supplied by the LASSSIE project consortium. Data was available at the planning region level. This allowed us to identify planning regions with an above-average number of LSMs, PROs and LSP and to group these planning regions into clusters.

Cooperation data used for this study came from two electronically available archive data sources: (I) The Foerderkatalog database provided by the German Federal Ministry of Education and Research (BMBF) and (II) the CORDIS databases provided by the European Community Research and Development Information Service (CORDIS). We are not the first to use these archive data sources to construct knowledge-related innovation networks (cf. (Broekel & Graf, 2011, p. 6; Fornahl et al. 2011; Scherngell & Barber, 2009; Scherngell & Barber, 2011; Cassi et al. 2008). There are solid arguments that advocate for the use of these archive data sources for analysing the evolution of innovation networks. Organizations that participate in R&D cooperation projects subsidized by the German federal state have to agree upon a number of regulations that facilitate mutual knowledge exchange and provide incentives to innovate (Broeckel & Graf, 2011, p. 6). In a similar vein, the EU has funded thousands of collaborative R&D projects in order to support transnational cooperation activities, increase mobility, strengthen the scientific and technological bases of industries and foster international competitiveness (Scherngell & Barber, 2009, p. 534). Both data sources provide exact information on the timing of the tie formation as well as the tie termination processes. In total, we gathered data on 570 publicly-funded cooperation projects.

The single-episode event history dataset for the German laser industry was constructed and organized as follows: Variables were grouped in the following categories: organizational, relational and contextual. An organizational variable was included in the dataset to account for differences in firm size [firmsize_cat_ev]. The following size categories were used: firmsize_cat_ev1 = "micro firm" = 1-9 employees; firmsize_cat_ev2 = "small firm" = 10-49 employees; firmsize_cat_ev3 = "medium firm" = 50-249 employees; firmsize_cat_ev4 = "large firms" = more than 250 employees. A simple relational variable was included in the dataset to account for the type of cooperation. Thus, nationally funded and supra-nationally funded R&D cooperation projects were coded separately [coop_type_ev]. The variable coop_type = 1 in the case of a CORDIS project; coop_type = 2 in the case of a Forderkatalog project. Occurrence dates and duration were recorded in century months. Finally, we included a set of cluster variables [clu_ev] in our dataset indicating whether a firm was located inside or outside of a densely crowded region. The four geographical clusters were identified and defined as follows: planning region: 72, 73, 74, 76 & 77 = clu-BW_ev, located in Baden-Württemberg; planning regions: 86, 90 & 93 = clu-Bay_ev, located in Bavaria: planning regions: 54 & 56 = clu-Thu_ev, located in Thuringia; planning region 30 = clu-B_ev, located in Berlin.

5 Empirical model specification and results

5.1 Empirical estimation approach

Non-parametric event history methods were used to test our hypotheses. For the purpose of this study, we applied the product-limit estimator, also known as the Kaplan-Meier method (Kaplan & Meier, 1958). This estimation method has several advantages: it is straightforward to use, requires only weak assumptions and allows non-repeated events in single-episode event history data to be analysed (Cleves et al. 2008, p. 93). The method estimates the survivor function based on longitudinal event data for all firms under risk (ibid.). In general, the survivor function represents the probability of surviving past time t, or to put it another way, the probability of failing after time t (ibid.). In this study we are interested in the German LSMs' propensity to cooperate for the first time. The unit of analysis is the firm. The time axis is defined on the basis of century months. All firm foundation dates as well as all start and end dates of cooperation events are given in century months. The event of interest is the first cooperation for all LSMs which are at risk in the time period between 1990 and 2010. The dataset allows us to analyse the transition from the origin state ("no-cooperation") to the destination state ("first cooperation"). Repeated events were not taken into account. Thus, the survival function has to be interpreted as follows: the survival function estimates a firms' probability of having the first cooperation event after time t.

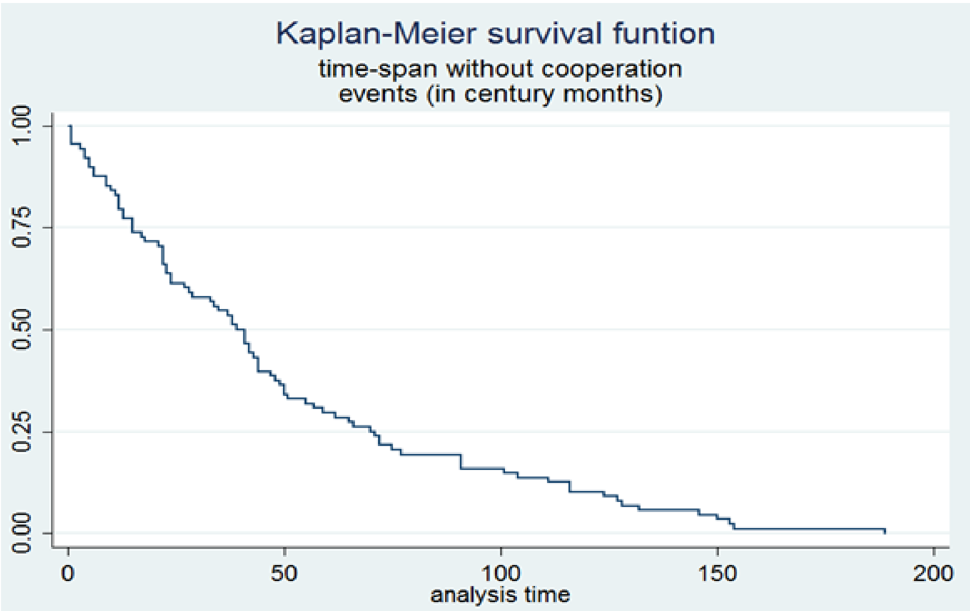
Non-parametric estimation methods provide the possibility of comparing survivor functions. The overall population can be divided into two or more subgroups by using an indicator variable to analyze whether the probability of failing after time t significantly differs among these subgroups. The indicator variable defines the membership in a particular subgroup (Blossfeld et al. 2007, p. 76). We apply this approach to analyse the extent to which organizational, relational and contextual determinants affect the cooperation behaviour over time.

For the purpose of this study we make use of the most commonly applied test statistics, i.e. the Log-Rank test, Cox test, Wilcoxon-Breslow test and Tarone-Ware test. These tests are designed to compare globally defined overall survival functions (Cleves et al. 2008, p. 123). Even though these tests provide relatively similar results in most cases, it can be useful to calculate and compare alternative test statistics. One reason for this is that some tests (e.g. Wilcoxon-Breslow) emphasize differences in survivor functions at the onset of the observation period whereas other test statistics (e.g. Log-Rank) stress differences at the end of the observation period (Blossfeld et al. 2007 p. 81). The Cox test is very similar to the Log-Rank test whereas the Tarone-Ware test, like the Wilcoxon-Breslow test, puts more weight on earlier time periods (ibid.). Common to all these test statistics is that they are χ^2-distributed with m-1 degrees of freedom. The tests are based on the null hypothesis that the survivor functions do not differ significantly from one another (Blossfeld et al. 2007, p. 81). A significant test result indicates that the null hypothesis must be rejected (ibid.). Or to put it another way, the rejection of the null hypothesis based on a significant test result supports the alternative hypothesis that the compared survivor functions differ significantly from one another.

5.2 Empirical results

A natural starting point is to look at the overall survivor function. Figure 3 shows that after 50 century months (i.e. 4 years and 2 months) about 66% of all firms in our sample have entered the network, while about 34% of all firms still were not able to initiate their first cooperation event. Only 50 century months later (i.e. 8 years and 4 months) about 84% have realized their first cooperation event and after 150 century months (i.e. 12 years and 6 months) 99.6% of all have firms moved from the origin state to the destination state.

Figure 3:
Timing to cooperate and enter the network

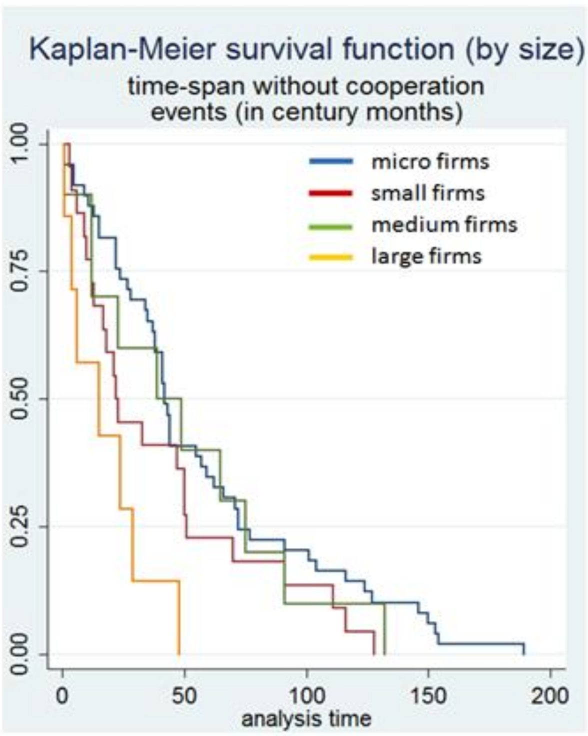


Source: Authors' own illustration.

To test our hypotheses we have used several indicator variables to split the sample, compare survivor functions and analysed the extent to which the probability of entering the network is affected by organizational, relational or contextual factors.

We start the presentation and discussion of our findings by looking at firm size. A comparison of survivor functions for micro, small, medium and large firms reveals some unexpected but quite interesting findings (Figure 4). What we observe is that micro firms enter the network significantly later than small and large firms. The sequence in which micro, small and large firms enter the network remains unchanged and stable throughout the entire observation period. The test statistic displayed to the right of the survivor function plot indicates that the null hypothesis have to be rejected, meaning that the survivor functions differ significantly from one another. These results seem to confirm, at least at first glance, our Hypothesis H1 according to which smaller firms have higher resource constraints and cooperate later than larger firms. However, the group of medium-sized firms complicates the story. At some points in time (e.g. after 50 months) medium-sized firms enter the network significantly later than both large firms as well as micro and small-sized firms. In a nutshell, we found only partial support for Hypotheses H1. The findings for micro, small and large firms are in line with our expectations. Moreover, the results clearly indicate that there must be another underlying process affecting the firms' timing to enter the network.

Figure 4:
Timing to cooperate and enter the network, by firm size



Log-rank test for equality of survivor functions

size categ	Events observed	Events expected		
10	49	57.97		
20	22	17.53		
30	10	9.97	chi2(3)=	11.05
40	7	2.53	Pr>chi2=	0.0499
Total	88	88.00		

Cox regression-based test for survival function equality

size categ	Events observed	Events expected	Relative hazard		
10	49	57.97	0.8674		
20	22	17.53	1.3254		
30	10	9.97	1.049	LR chi2(3)	8.26
40	7	2.53	3.0565	Pr>chi2 =	0.0409
Total	88	88	1		

Wilcoxon (Breslow) test for survivor function equality

size categ	Events observed	Events expected	Sum of ranks		
10	49	57.97	-496		
20	22	17.53	233		
30	10	9.97	-26	chi2(3) =	9.97
40	7	2.53	289	Pr>chi2 =	0.0188
Total	88	88	0		

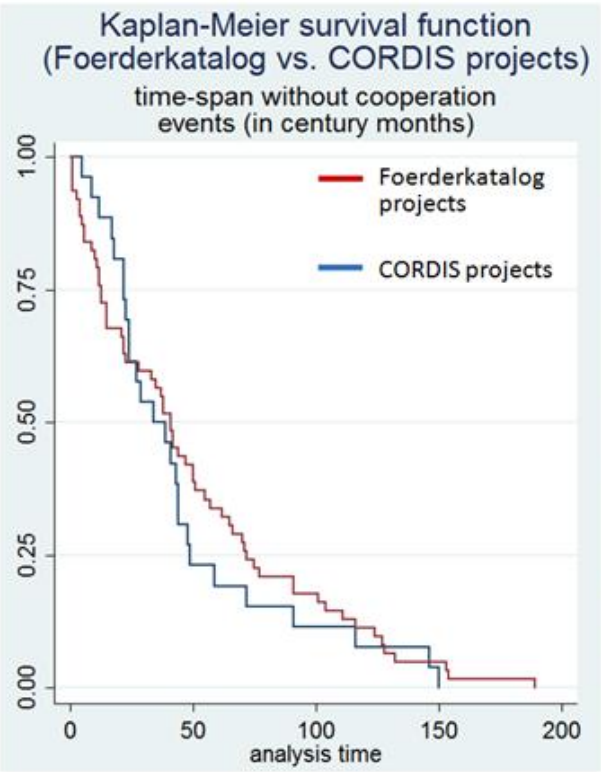
Tarone-Ware test for equality of survivor functions

size categ	Events observed	Events expected	Sum of ranks		
10	49	57.97	-62.7301		
20	22	17.53	30.03659		
30	10	9.97	-2.7859	chi2(3) =	10.42
40	7	2.53	35.47945	Pr>chi2 =	0.0153
Total	88	88	0		

Source: Authors' own illustration.

Next, we look at the relational dimension. Our first intuition was that the type of cooperation used by a firm to enter the network is likely to affect how long it would take for the first cooperation event to occur. Surprisingly, a comparison of nationally and supra-nationally funded R&D projects shows no significant differences (Figure 5). All four test statistics indicate that the null hypothesis must be confirmed, meaning that there is no significant difference between the compared survivor functions. In other words, it makes no difference whether a firm favours nationally funded (i.e. Foerderkatalog projects) or supra-nationally funded (i.e. CORDIS projects) R&D projects. The problem of "double layered acculturation" inherent to international cooperation projects (Barkema et al. 1997, p. 154) seems to play no significant role in this context. As a consequence we have to reject our Hypotheses H2. One potential explanation for this result could be that the previously existing interpersonal network between decision makers relativizes culturally contingent cooperation barriers.

Figure 5:
Timing to cooperate and enter the network, by cooperation type



Log-rank test for equality of survivor functions

fk_c_dum	Events observed	Events expected		
0	26	23.79	chi2(1)=	0.29
1	62	64.21	Pr>chi2=	0.5874
Total	88	88.00		

Cox regression-based test for equality of survival curves

fk_c_dum	Events observed	Events expected	Relative hazard		
0	26	23.79	1.0971	LR chi2(1)=	0.28
1	62	64.21	0.9662	Pr>chi2 =	0.5948
Total	88	88	1		

Wilcoxon (Breslow) test for equality of survivor functions

fk_c_dum	Events observed	Events expected	Sum of ranks		
0	26	23.79	-5	chi2(1) =	0.00
1	62	64.21	5	Pr>chi2 =	0.9820
Total	88	88.00			

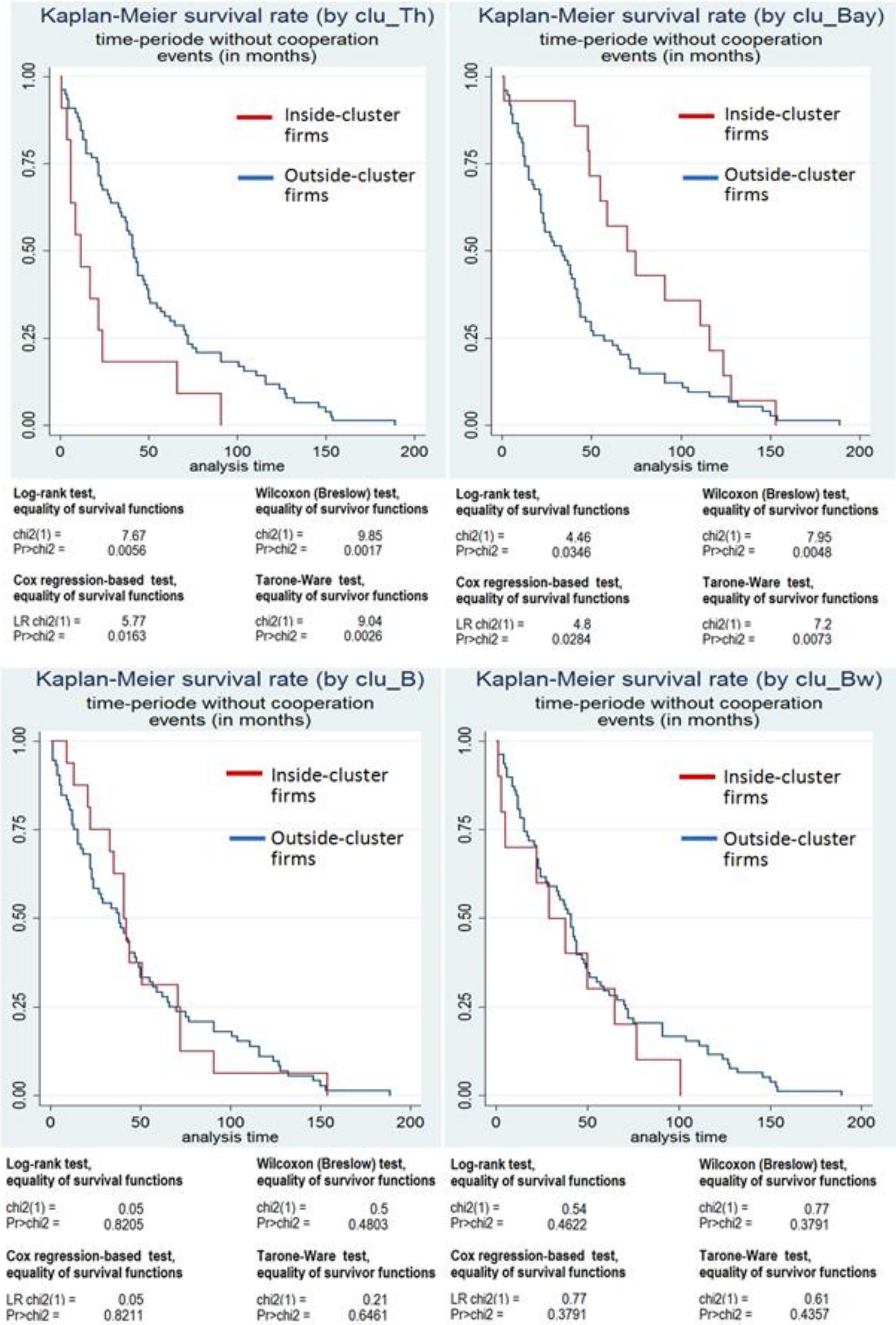
Tarone-Ware test for equality of survivor functions

fk_c_dum	Events observed	Events expected	Sum of ranks		
0	26	23.79	7.496826	chi2(1) =	0.07
1	62	64.21	-7.49683	Pr>chi2 =	0.791
Total	88	88	0		

Source: Authors' own illustration.

Finally, we address here only one among several other contextual determinants by taking a closer look at the geographical proximity dimension. To analyse as to what extant cluster membership affects a firm's timing for entering the network we identified several planning regions with an above-average number of LSMs, PROs and LSPs and grouped them to four clusters: cluster_Th, cluster_Bay, cluster_B, cluster_Bw.

Figure 6:
Timing to cooperate and enter the network, by cluster membership



Source: Authors' own illustration.

Figures 6 illustrate our empirical results. Maybe the most interesting finding is that cluster membership can have quite different effects on the firms’ timing to enter the network. Results show that firms located in the Thuringia Cluster (clu_Th) cooperate significantly earlier than firms located elsewhere. Exactly the opposite is true for firms located in the Bavarian Cluster (clu_Bay). In both cases test statistics indicate that the compared survivor functions for inside-cluster and outside-cluster firms differ significantly. However, this is only half of the story. Our results for the Berlin Cluster (clu_B) and the Bavarian Cluster (Clu_Bw) reveal a quite different picture. In both cases we found no empirical evidence for significantly different survivor functions when comparing inside-cluster and outside-cluster firms. In summary, clusters can, but do not necessarily, affect the firm’s timing for cooperating and entering the network. Thus, we found empirical support for each of the three cases proposed in Hypothesis H3.

6 Conclusion and further research

This study was motivated by a desire to deepen our understanding of how interorganizational innovation networks evolve. This quite demanding task was approached from two directions. On the one hand we proposed a conceptual framework that consists of thee elementary building- block – (I) “determinants”, (II) “micro level network change processes” and (III) “structural consequences” – to provide the theoretical basis for an in-depth analysis of evolutionary network change. On the other hand we conducted a non-parametric event history analysis to provide some empirical evidence on LSMs’ propensity to cooperate for the first time and enter the German laser industry innovation network. The empirical analysis provides some evidence that micro firms enter the network significantly later than small-sized and large firms but fails to explain the late entry of medium sized firms. In addition, results shows that the choice of cooperation type has no significant impact on a firm’s timing in entering the network and reveals that cluster membership can, but does not necessarily, affect a firm’s timing to cooperate. Despite these initial steps towards a deeper understanding of network change, we still face some considerable challenges.

From a theoretical perspective a lot remains to be done. For instance, our conceptual framework still requires some further refinement. Organizational, relational and contextual determinates have to concretized and interdependencies between these three dimensions have to be addressed more explicitly. One interesting study that tends towards this direction is the study by Hagedoorn (2006). Moreover, we included a very specific type of network path dependence in our framework to account for a network entrant’s cooperation behavior in the subsequent cooperation rounds. We refer to this idea as “cooperation imprinting”. We believe that the sequential analysis of cooperation strategies and cooperation options is crucial for understanding structural network change. The refinement of this idea constitutes one of the next steps in our research agenda.

From an empirical point of view we are still at an early stage. This study concentrates exclusively on a firm's first cooperation event. In other words, the empirical part of our paper is restricted to processes that solely affect potential network entrants. Cooperation events between incumbents were not addressed. Consequently, the next steps in our research agenda are straight forward. Firstly, we will include repeated cooperation events in our empirical analysis. Secondly, we have to find a way to analyze the structural consequences of micro-level network change processes empirically. Finally, our database has to be extended in several ways to get a comprehensive empirical basis for the analysis of evolutionary network change processes. Currently, we are proceeding in this direction by including non-funded strategic alliances in our database.

The methods used in this study provide a good starting point for an exploratory analysis of network change processes but they are limited in several ways. Both parametric and semi-parametric estimation approaches provide a broad range of empirical models that can be used for an in-depth analysis of tie-formation and tie termination processes at the firm level. In addition, other powerful methods are now available such as agent-based simulation approaches. For instance, the so-called KENE approach (Gilbert 1997, Gilbert et al. 2001, Gilbert et al. 2007, Pyka et al. 2007) allows a firm's knowledge base, learning processes and the transfer of knowledge in complex network structures to be modeled and simulated. These types of agent-based models can be applied to simulate micro level firm behaviour which shapes the macro level network patterns (Mueller et al. 2012). Another promising avenue is to apply stochastic agent based models (Snijders et al. 2010) in order to gain a more profound understanding of how and why interorganizational innovation networks change over time.

REFERENCES

Ackerlof, G. A. (1970): The market for "lemons". Quality uncertainty and the market mechanism. Quarterly Journal of Economics, 84 (3), pp. 488-500.

Albert, R., & Barabasi, A.-L. (2002): Statistical mechanics of complex networks. Reviews of Modern Physics, 74(1), pp. 47-97.

Aldrich, H. E., & Ruef, M. (2006): Organizations evolving (2nd ed.). London: Sage Publications.

Allison, P. D. (1984): Event history analysis - regression for longitudinal event data . London: Sage Publications.

Amburgey, T. L., & Rao, H. (1996): Organizational ecology: past, present, and future directions. Academy of Management Journal, 39(5), pp. 1265-1286.

Amburgey, T. L., & Singh, J. V. (2005): Organizational evolution. In J. A. Baum, The Blackwell Compenion to Organizaions (pp. 327-343). Malden MA: Blackwell Publishing.

Amburgey, T. L., Al-Laham, A., Tzabbar, D., & Aharonson, B. S. (2008): The structural evolution of multiplex organizational networks: research and commerce in biotechnology. In J. A. Baum, & T. J. Rowley, Advances in Strategic Management - Network Strategy (Vol. 25, pp. 171-212). Bingley UK: Emerald Publishing.

Amburgey, T., & Al-Laham, A. (2005): Islands in the net. Conference paper: 22nd EGOS Colloquium, Bergen, pp. 1-42.

Amburgey, T., Aharonson, B. S., & Tzabbar, D. (2009): Heterophily in inter-organizational network ties. Conference paper: 25th EGOS Colloquium, Barcelona.

Arino, A., & De La Torre, J. (1998): Learning from failure: towards an evolutionary model of collaborative ventures. Organization Science, 9(3), pp. 306-325.

Arthur, B. W. (1989): Competing technologies, increasing returns, and lock-in by historical events. The Economic Journal, 99(394), pp. 116-131.

Audretsch, D. B., & Feldman, M. P. (1996): R&D spillovers and the geography of innovation and production. American Economic Review , 86 (3), pp. 630-640.

Barabasi, A.-L., & Albert, R. (1999): Emergence of scaling in random networks. Sience, 286(15), pp. 509-512.

Barney, J. B. (1991): Firm resources and sustained competitive advantage. Journal of Management, 17 (1), pp. 99-120.

Barron, D. N., West, E., & Hannan, M. T. (1994): A time to grow and a time to die: growth and mortality of Credit Unions in New York City, 1914-1990. American Journal of Sociology, 100 (2), pp. 381-421.

Barkema, H. G., Bell, J. H., & Pennings, J. M. (1996): Foreign Entry, Cultural Barriers, and Learning. Strategic Management Journal, 17 (2), pp. 151-166.

Baum, J. A., Calabrese, T., & Silverman, B. S. (2000): Don't go it alone: alliance network composition and startup's performance in Canadian biotechnology. Strategic Management Journal, 21(3), pp. 267-294.

Baum, J. A., Shipilov, A. W., & Rowley, T. J. (2003): Where do small worlds come from? Industrial and Corporate Change, 12(4), pp. 697-725.

Betton, J., & Dess, G. G. (1985): The application of population ecology models to the study of organizations. Academy of Management Review, 10(4), pp. 750-757.

Blossfeld, H.-P., & Rohwer, G. (2002): Techniques of event history analysis - new approaches to causal analysis. London: Lawence Erlbaum Associates Publishing.

Blossfeld, H.-P., Golsch, K., & Rohwer, G. (2007): Event history analysis with Stata. London: Lawrence Erlbaum Associates, Publishers.

Boschma, R. (2005): Proximity and innovation: a critical assessment. Regional Studies, 39(1), pp. 61-74.

Boschma, R., & Frenken, K. (2010): The spatial evolution of innovation networks: a proximity perspective. In R. Boschma, & R. Martin, The Handbook of Evolutionary Economic Geography (pp. 120-135). Cheltenham: Edward Elgar Publishing.

Brenner, T., Cantner, U., & Graf, H. (2011): Innovation networks: measurement, performance and regional dimensions. Industry & Innovation, 18(1), pp. 1-5.

Broekel, T., & Graf, H. (2011): Public research intensity and the structure of German R&D networks: A comparison of ten technologies. Economics of Innovation and New Technology, pp. 1-28.

Buenstorf, G. (2007): Evolution on the shoulders of giants: entrepreneurship and firm survival in the German laser industry. Review of Industrial Organization, 30(3), pp. 179-202.

Campbell, D. T. (1969): Variation and selective retention in sociocultural evolution. Genaral Systems, 16, pp. 69-85.

Carroll, G. R. (1984): Organizational ecology. Annual Review of Sociology, 10, pp. 71-93.

Cassi, L., Corrocher, N., Malerba, F., & Vonortas, N. (2008): Research networks as infrastructure for knowledge diffusion in European regions. Economics of Innovation and New Technology, 17(7), pp. 665-678.

Cleves, M. A., Gould, W. W., Gutierrez, R. G., & Marchenko, Y. U. (2008): An introduction to survival analysis using Stata (2 ed.). College Station: Stata Press.

Coff, R. W. (2003): The emergent knowledge-based theory of competetive advantage: an evolutionary approach to integrating economics and management. Managerial and Decision Economics, 24(4), pp. 245-251.

Cooke, P. (2001): Regional innovation systems, clusters, and the knowledge economy. Industrial and Corporate Change, 10(4), pp. 945-974.

Cowan, R., Jonard, N., & Zimmermann, J.-B. (2006): Evolving networks of inventors. Journal of Evolutionary Economics, 16(1), pp. 155-174.

Dacin, T. M., Hitt, M. A., & Levitas, E. (1997): Selecting partners for successfull international alliances: examination of U.S. and Korean firms. Journal of World Business , 32 (1), pp. 3-16.

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

De Rond, M., & Bouchiki, H. (2004): On the dialectics of strategic alliances. Organization Science, 15(1), pp. 56-69.

Dierickx, I., & Cool, K. (1989): Asset stock accumulation and sustainability of competitive advantage. Management Science , 35 (12), pp. 1504-1511.

Dopfer, K. (2005): The evolutionary foundation of economics. Cambridge: Cambridge University Press.

Dopfer, K., Foster, J., & Potts, J. (2004): Micro–meso–macro. Journal of Evolutionary Economics, 14(3), pp. 263-279.

Doreian, P., & Stokman, F. N. (2005): The dynamics and evolution of social networks. In P. Doreian, & F. N. Stokman, Evolution of Social Networks (2nd ed., pp. 1-17). New York: Gordon and Breach.

Doreian, P. (2008): Actor utilities, strategic action and network evolution, in: In J. A. Baum, & T. J. Rowley, Advances in Strategic Management - Network Strategy (Vol. 25, pp. 247-271). Bingley UK: Emerald Publishing.

Doz, Y. L. (1996): The evolution of cooperation in strategic alliances: initial conditions or learning processes? Strategic Management Journal, 17(1), pp. 55-83.

Dwyer, R. F., Schurr, P. H., & Oh, S. (1987): Developing buyer-seller relationships. Journal of Marketing, 51(2), pp. 11-27.

Elfring, T., & Hulsink, W. (2007): Networking by entrepreneurs: patterns of tie formation in emerging organizations. Organization Studies, 28(12), pp. 1849-1872.

Feldman, M. P. (1999): The new economics of innovation, spillovers and agglomeration: a review of empirical studies. Economics of Innovation and New Technology, 8(1), pp. 5-25.

Fornahl, D., Broeckel, T., & Boschma, R. (2011): What drives patent performance of German biotech firms? The impact of R&D subsidies, knowledge networks and their location. Papers in Regional Science, 90(2), pp. 395-418.

Forrest, J. E., & Martin, M. J. (1992): Strategic alliances between large and small research intensive organizations: experiences in the biotechnology industry. R&D Management, 22(1), pp. 41-53.

Freeman, C. (1991). Networks of innovators: a synthesis of research issues. Research Policy, 20(5), pp. 499-514.

Fritsch, M., & Medrano, L. (2010): The spatial diffusion of a knowledge base – laser technology research in West Germany, 1960 – 2005. Jena Economic Research Papers, pp. 1-52.

Gilbert N, Pyka A & Ahrweiler P (2001): Innovation networks - a simulation approach. Journal of Artificial Societies and Social Simulation, 4(3), pp.1-13.

Gilbert N, Ahrweiler P & Pyka A (2007): Learning in innovation networks: Some simulation experiments. Physica A: Statistical Mechanics and its Applications, 378(1), pp. 100-109.

Glueckler, J. (2007): Economic geography and the evolution of networks. Journal of Economic Geography, 7(5), pp. 619-634.

Goerzen, A. (2005): Managing alliance networks: emerging practices of multinational corporations. Academy of Management Executive, 19(2), pp. 94-107.

Grant, R. M., & Baden-Fuller, C. (2004): A knowledge accessing theory of strategic alliances. Journal of Management Studies, 41(1), pp. 61-84.

Grupp, H. (2000): Learning in a science driven market: the case of lasers. Industrial and Corporate Change, 9(1), pp. 143-172.

Guimera, R., Uzzi, B., Spiro, J., & Armaral, L. A. (2005): Team assembly mechanisms determine collaboration network structure and team performance. Science, 308(29), pp. 697-702.

Gulati, R. (1995): Social structure and alliance formation pattern: a longitudinal analysis. Administrative Science Quarterly, 40(4), pp. 619-652.

Gulati, R., & Gargiulo, M. (1999): Where do interorganizational networks come from? American Journal of Sociology, 104(5), pp. 1439-1493.

Gulati, R. (2007): Managing network resources - alliances, affiliations and other relational assets. New York: Oxford University Press.

Gunasekaran, A. (1997): Essentials of international and joint R&D projects. Technovation , 17, pp. 637-647.

Hagedoorn, J. (2006): Understanding the cross-level embeddedness of interfirm partnership formation. Academy of Management Review, 31(3), pp. 670-680.

Hakansson, H., & Johanson, J. (1988): Formal and informal cooperation - strategies in international industrial networks. In F. J. Contractor, & P. Lorange, Cooperative Strategies in International Business (pp. 369-379). Mass.: Lexington Books.

Hakansson, H., & Snehota, I. (1995): Stability and change in business networks. In H. Hakansson, & I. Snetota, Developing relationships in business networks (pp. 24-49). London: Thomson.

Halinen, A., Salmi, A., & Havila, V. (1999): From dyadic change to changing business networks: an analytical framework. Journal of Management Studies, 36(6), pp. 779-794.

Hamel, G. (1991): Competition for competence and inter-partner learning within international strategic alliances. Strategic Management Journal, 12(1), pp. 83-103.

Hannan, M. T., & Freeman, J. (1977): The population ecology of organizations. American Journal of Sociology, 82(5), pp. 929-964.

Hanusch, H., & Pyka, A. (2007): Principles of Neo-Schumpeterian economics. Cambridge Journal of Economics, 31(2), pp. 275-289.

Hofstede, G. (2001): Culture's consequences: comparing values, behaviors, institutions, and organizations across nations (2nd ed.). Thousand Oaks, California: Sage Publications.

Jackson, M. O., & Watts, A. (2002): The evolution of social and economic networks. Journal of Economic Theory, 106(2), pp. 265-295.

Jeong, H., Neda, Z., & Barabasi, A.-L. (2003): Measuring preferential attachment in evolving networks. Europhysics Letters, 61(4), pp. 567-572.

Johanson, J., & Mattson, L.-G. (1988): Internationalization in industrial systems - a network approach. In N. Hood, & J.-E. Vahlen, Strategies in Global Competition (pp. 287-331). New York: Croom Helm.

Jun, T., & Sethi, R. (2009): Reciprocity in evolving social networks. Journal of Evolutionary Economics, 19(3), pp. 379-396.

Kaplan, E. L., & Meier, P. (1958): Nonparametric estimation from incomplete observations. Journal of the American Statistical Association, 53, pp. 457-481.

Kenis, P., & Knoke, D. (2002): How organizatinal field networks shape Interorganizational tie-formation rates. Academy of Management Review, 27(2), pp. 275-293.

Kenis, P., & Oerlmans, L. (2008): The social network perspective - understanding the structure of cooperation. In S. Cropper, M. Ebers, C. Huxham, & P. S. Ring, The Oxford Handbook of Inter-Organizational Relations (pp. 289-312). New York: Oxford University Press.

Kirman, A. (1993): Ants, rationality, and recruitment. The Quarterly Journal of Economics, 108(1), pp. 137-156.

Klepper, S. (1997): Industry life cycles. Industrial and Corporate Change, 6(1), pp. 145-181.

Kudic, M., Guhr, K., Bullmer, I., & Guenther, J. (2011): Kooperationsintensität und Kooperationsförderung in der deutschen Laserindustrie. Wirtschaft im Wandel, 17(3), pp. 121-129.

Larson, A. (1992): Network dyads in entrepreneurial settings: a study of the governance of exchange relationships. Administrative Science Quarterly, 37(3), pp. 76-104.

Lavie, D., & Miller, S. R. (2008): Alliance portfolio internationalization and firm performance. Organization Science, 19(4), pp. 623-646.

Levitt, T. (1965): Exploit the product life cycle. Harvard Business Review, 43(6), pp. 81-94.

Lorenzoni, G., & Ornati, O. A. (1988): Constellations of firms and new ventures. Journal of Business Venturing, 3(1), pp. 41-57.

Lu, J. W., & Beamish, P. W. (2006): Partnering strategies and performance of SMEs' international joint ventures. Journal of Business Venturing, 21 (4), pp. 461-486.

Malerba, F. (2002): Sectoral systems of innovation and production. Research Policy, 31(2), pp. 247-264.

Mayer, A. (2004): Laser in der Materialbearbeitung - Eine Marktübersicht. Laser Technik Journal, 1(1), pp. 9-12.

McPherson, M., Smith-Lovin, L., & Cook, J. M. (2001): Birds of a feather: homophily in social networks. Annual Review of Sociology, 27(1), pp. 415-444.

Menzel, M.-P., & Fornahl, D. (2009): Cluster life cycles - dimensions and rationales of cluster evolution. Industrial and Corporate Change, 19(1), pp. 205-238.

Mueller, M., Buchmann, T. & Kudic, M. (2012): Micro Strategies and Macro Patterns in the Evolution of Innovation Networks – An Agent-Based Simulation Approach. Conference paper, 2nd SKIN Workshop, Koblenz, Germany, pp. 1-33.

Murray, E. A., & Mahon, J. F. (1993): Strategic alliances: gateway to new Europe. Long Range Planning, 26(4), pp. 102-111.

Nakamura, M., Vertinsky, I., & Zietsam, C. (1997): Does culture matter in inter-firm cooperation? Research consortia in Japan and the USA. Managerial and Decision Economics, 18, pp. 153-175.

Nelson, R. R., & Winter, S. G. (2002): Evolutionary theorizing in economics. Journal of Economic Perspectives, 16(2), pp. 23-46.

Newman, M. E. (2010): Networks - an introduction. New York: Oxford University Press.

Nowak, M. A., Tarnita, C. E., & Antal, T. (2010): Evolutionary dynamics in structured populations. Philosophical Transansitions in the Royal Society B, 365(1537), pp. 19-30.

Owen-Smith, J., Riccaboni, M., Pammolli, F., & Powell, W. W. (2002): A comparison of U.S. and European University-Industry relations in the Life Sciences. Management Science , 48 (1), pp. 24-43.

Ozman, M. (2009): Inter-firm networks and innovation: a survey of literature. Economics of Innovation and New Technology, 18(1), pp. 39-67.

Parkhe, A., Wasserman, S., & Ralston, D. A. (2006): New frontiers in network theory development. Academy of Management Review, 31(3), pp. 560-568.

Peteraf, M. A. (1993): The cornerstones of competitive advantage: A resource-based view. Strategic Management Journal , 14 (3), pp. 179-191.

Pittaway, L., Robertson, M., Munir, K., Denyer, D., & Neely, A. (2004): Networking and innovation: a systematic review of the evidence. International Journal of Management Reviews, 5(6), pp. 137-168.

Powell, W. W., White, D. R., Koput, K. W., & Owen-Smith, J. (2005): Network dynamics and field evolution: the growth of the interorganizational collaboration in the life sciences. American Journal of Sociology, 110(4), pp. 1132-1205.

Pyka, A. (2002): Innovation networks in economics: from the incentive-based to the knowledge based aproaches. European Journal for Innovation Management, 5(3), pp. 152-163.

Pyka A, Gilbert N & Ahrweiler P (2007): Simulating Knowledge-Generation and Distribution Processes in innovation collaborations and networks. Cybernetics and Systems: An International Journal, 38(7), pp. 667-693.

Ring, P. S., & Van De Ven, A. H. (1994): Developmental processes of cooperative interorganizational relationships. Academy of Management Review, 19(1), pp. 90-118.

Rosenkopf, L., & Tushman, M. L. (1998): The coevolution of community networks and technology: lessons from the flight simulation industry. Industrial and Corporate Change, 7(2), pp. 311-346.

Scherngell, T., & Barber, M. J. (2009): Spatial interaction modelling of cross-region R&D collaborations: empirical evidence from the 5th EU framework programme. Papers in Regional Science, 88(3), pp. 531–546.

Scherngell, T., & Barber, M. J. (2011): Distinct spatial characteristics of industrial and public research collaborations: evidence from the fifth EU framework programme. Annals of Regional Science, 46(2), pp. 247-266.

Schilke, O., & Goerzen, A. (2010): Alliance management capability: an investigation of the construct and its measurement. Journal of Management, 36(5), pp. 1192-1219.

Schilling, M. A. (2009): Understanding the alliance data. Strategic Management Journal, 30(3), pp. 233-260.

Schwerk, A. (2000): Dynamik von Unternehmenskooperationen. Berlin: Duncker & Humbolt.

Snijders, T. A., Van De Bunt, G. G., & Steglich, C. E. (2010): Introduction to actor-based models for network dynamics. Social Networks, 32(1), pp. 44-60.

Soda, G., & Zaheer, A. (2004): Network memory: the influence of past and current networks on performance. Academy of Management Journal, 47(6), pp. 893-906.

Spence, M. (1976): Informational aspects of market structure: an introduction. Quarterly Journal of Economics , 90 (4), pp. 591-597.

Stokman, F. N., & Doreian, P. (2005): Evolution of social networks: processes and principles. In P. Doreian, & F. N. Stockman, Evolution of Social Networks (2nd ed., pp. 233-251). New York: Gordan Breach.

Sydow, J. (2003): Dynamik von Netzwerkorganisationen - Entwicklung, Evolution, Strukturation. In W. H. Hoffmann, Die Gestaltung der Organisationsdynamik - Konfiguration und Evolution (pp. 327-357). Stuttgart: Schäffer-Poeschel.

Ter Wal, A. L., & Boschma, R. (2011): Co-evolution of firms, industries and networks in space. Regional Studies, 45(7), pp. 919-933.

Tiberius, V. (2008): Prozesse und Dynamik des Netzwerkwandels. Wiesbaden: Gaber.

Van De Ven, A. H., & Poole, M. S. (1995): Explaining development and change in organizations. Academy of Management Review, 20(3), pp. 510-540.

Venkatraman, S., & Lee, C.-H. (2004): Preferential linkage and network evolution: a conceptual model and empirical test in the U.S. video game sector. Academy of Management Journal, 47(6), pp. 876-892.

Walker, G., Kogut, B., & Shan, W. (1997): Social capital, structural holes and the formation of an industry network. Organization Science, 8(2), pp. 109-125.

Wasserman, S., & Faust, K. (1994): Social network analysis: methods and applications. Cambridge: Cambridge University Press.

Wernerfelt, B. (1984): A resource based view of the firm. Strategic Management Journal, 5 (2), pp. 171-180.

Witt, U. (2008): Recent developments in evolutionary economics. Cheltenham: Edward Elgar Publishing.

Zaheer, A., & Soda, G. (2009): Network evolution: the origins of structural holes. Administrative Science Quarterly, 54(1), pp. 1-31.