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Cliques within Clusters –

Multi-dimensional Network Integration and Innovation Activities

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Abstract

Regional industrial clusters have certainly been one of the most prominent loci where competition meets cooperation. Not surprisingly, the coexistence of these two phenomena is a constitutive feature of most cluster definitions. Nevertheless, the micro-dynamics of clusters with respect to these and other processes are still little understood, especially regarding one of the most important outcomes of clusters – innovation. The present paper aims at enhancing our understanding of how clusters are conducive to innovation by investigating the micro-structures and -processes of an emerging optics/photonics cluster in Germany using a broad range of research methodologies, including clique analysis and participant observation. The results confirm the expectation that the micro-structures that have actually emerged in the cluster do not entirely correspond to the formal cluster governance and that multiplex overlapping cliques provide not only for a fair amount of network integration, but also a social context conducive for turning complex knowledge of research organizations into marketable products. While questioning such unidirectional effects, the generation of innovation can also be understood as a medium for generating and stabilizing such relational structures – even between competitors within clusters.

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Introduction: Networks, Clusters and Innovation

Involvement in a cluster of firms operating within the same industry is believed to be conducive to the innovativeness of firms within the cluster (Porter 1990; Harrison 1994). More precisely, research institutes, customers and suppliers of products and services, as well as associated institutions interacting with each other in a cluster have been shown to be more innovative than those operating outside such a regional agglomeration that is characterized by a critical mass of specialized but interconnected organizations that co-operate but also compete (Porter 1998; Enright 2003). However, the question arises, which structures and processes in a cluster really enhance the competitiveness of organizations and, hence, produce the desired network-level outcomes. Candidates are the presence of specific actors like local customers, innovative manufacturers, qualified suppliers, including competitors; abundant resources (i.e. human and financial capital); the evolution of relational structures among these actors ensuring sufficient integration; and processes fostering knowledge spillovers, especially the transfer of complex knowledge. However, cluster research, in the industrial economics tradition in particular, has so far been rather blind with regard to micro-level structures and -processes generating cluster- or network-level outcomes like innovation.

Starting from the assumption that interorganizational interaction is decisive for innovation and that organizations interacting, in a high-tech cluster in particular, tend to form interorganizational networks for integrating their specialized activities, we look into the micro-dynamics of unfolding interorganizational collaboration in the case of an emerging optics/photonics cluster in the Berlin-Brandenburg region in Germany. For it may well be that these networks, or other substructures of clusters that result from interorganizational differentiation and integration, are the real loci of innovation, while the overall cluster is only supportive of their development. Though interorganizational interaction on the level of the entire cluster may actually be quite helpful in order to lobby for local political support, to get to know each other or even to develop a “regional industrial identity” (Romanelli & Khessina 2005), more concrete, often project-based interorganizational collaboration, between small and medium-sized enterprises and research organizations in particular, may be necessary for pooling and transferring often complex tacit knowledge and developing new technological knowledge that can be patented and, finally, marketed. This is particularly true in high-tech and dynamic fields such as photonics, where collaborating or networking between research institutes and business firms bridges not only different organizations, but also two distinct “societal spheres” (Giddens 1984), that of science on the one hand and that of economics on the other (cf. Sydow & Windeler 2003).

Having observed the emergence and management of the photonics cluster in Berlin-Brandenburg over a period of more than five years, we apply clique analysis (Wasserman & Faust 1994: 249-290) on quantitative relational data that we collected for 2003 as well as for 2000, just before the cluster was formally set-up. The aims of this analysis are to disclose the actual network relations that comprise a particular formal cluster governance, to detect relevant cohesive substructures in the cluster and analyze how these structures overlap, and finally to explore what this kind of network integration means for innovation activities. More specifically, we wish to uncover for our sample whether Provan & Sebastian (1998) are right that "network effectiveness may owe far less to integration across a network as a whole than to ties among a few organizations that provide the bulk of relationships and network success is likely to be the result of effective interaction among small, overlapping subsets of [organizations]" (454). This may not only hold true for network effectiveness in general but for innovation activities in particular.

Overall, the paper contributes to a deeper understanding of micro-structures and micro-processes of regional clusters by looking at the relationships between formal cluster governance and actual networks of relationships and between multi-dimensional network integration and innovation activities. To this end it applies a multi-level analysis that distinguishes the cluster level from network and clique levels and accounts for the recursive interplay between structural properties of these levels and how agents refer to them in interorganizational interactions. Thereby, this study adds to the very few studies of interorganizational networks that analyze cliques and their overlap (e.g. Provan & Sebastian 1998), but goes beyond them, first, by using longitudinal quantitative data and, second, by using insights from qualitative interviews and participant observations over a period of five years, both of which allow for studying network dynamics.

Cliques, Network Integration and Innovation: Theorizing Interorganizational Relationships

Though clique analysis is an excellent methodology for detecting actual structures and cohesive and arguably effective sub-groups in complex networks (see Kilduff & Tsai, 2003: 44-49), it has rarely been applied in the study of the effectiveness of interorganizational networks in general (see Provan & Sebastian, 1998 for an exception) and of clusters in particular. This is surprising, given that clique analysis is anything but new and provides access to an intermediary level of analysis – that between the cluster/field on the one hand and single organizations on the other. In more colloquial terms, clique analysis provides a structural focus on where the (inter-) action is. The analysis of how cliques overlap allows, in addition, for studying the internal structuring of sub-groups within a network (Wasserman & Faust 1994) and, thereby, for illuminating the relation between network integration and effectiveness. From a practitioner's point of view, not only cliques but well functioning clique overlap may be used as a *leitbild* for developing (other parts of) the cluster or field.

Formal Network Governance and Actual Network Relationships: Rules and Practices

Both cliques and clique overlap disclose how network relationships have emerged in reality. More specifically, establishing the level of network integration using these structural measures makes it possible to shed some light on the extent to which these relationships actually reflect the formal governance of a cluster. In the case of clusters, this governance structure usually comprises the legal set-up (e.g. the choice between a corporation and an association as well as between a single executive and a board), the system of formal rules (including contractual arrangements) coordinating the network member activities, and, maybe, the establishment of sub-clusters in order to foster the (informal) exchange of technological information and knowledge, or to initiate cooperative innovation projects.

Especially in large and complex networks, like industry clusters, heterogeneous sub-groups and practices are likely to emerge that only in part reflect these formal governance structures. One important reason is that industry clusters are typically rather decentralized, polycentric systems resembling to some extent "organic" structures of innovative organizations (Burns & Stalker 1961). Moreover, the sub-systems of a cluster may be exposed to quite different environments, which may be reflected in the rather diverse interorganizational structures, formal rules and informal practices. This might be especially true in dynamic and rapidly expanding industries with a dispersed knowledge base not only characteristic of the biotech industry (Powell, Koput & Smith-Doerr 1996) but also of the field of photonics, which is often characterized as an enabling technology (see, for example, National Research Council 1998). In the quest to be at the competitive edge, research institutes and companies in this field increasingly exploit interdisciplinary approaches to innovation resulting in interaction between actors not only from distinct societal spheres, but also from different technological disciplines within and outside the regional cluster. These arguments lead us to propose that the photonics cluster we study – and the association that now comprises more than 90 organizations – will have actually formed quite different substructures, thus producing more heterogeneity than originally intended by the formal cluster governance (Proposition 1).

Innovation and Network Integration: The Role of Cliques and Clique Overlap

Most research suggests that densely interconnected "closed" networks are advantageous for those network actors that maintain many connections (Coleman 1988; Walker, Kogut & Shan 1997). In contrast, Burt (1992) stresses the entrepreneurial generation and exploitation of structural holes between densely connected regions in networks. Analysis of densely interconnected (regions of) networks and measuring of network integration can be done on the most general level by using network density scores.[1] However, the value of overall network density measures is limited if, as in our case, the number of nodes in the sub-groups or -networks is significantly different. Moreover, and in line with the findings of Burt (1992) and Provan & Sebastian (1998), there is not always a need for network-wide integration. Rather, complex networks such as clusters may quite effectively be integrated by overlapping cliques. Recent studies of cohesiveness, used as an indicator of the embeddedness of networks (Moody & White 2003), further reveal that benefits lie in the membership in coherent network components.

In Consequence, the identification of substructures within larger and more complex networks is a central interest in the analysis of network differentiation and integration. As early empirical studies (i.e. the Bank Wiring Room study by Roethlisberger/Dickson 1939; the school class analysis by Moreno 1934) showed, social networks can be conceptualized as being built up of a number of more closely connected substructures. Clique and component concepts identify cohesive subgroups and larger compounded sub-groupings in networks and generate sub-graphs that overlap[2] (see Everett & Borgatti 1998) indicating more integrated regions in a network.

A clique can be defined as a sub-set of at least three actors in which every possible pair of points is directly connected by a line and the clique is not contained in any other clique (Was-

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[1] The density of a network represents the relation between the number of links in a given network as compared to the maximum possible number of links n(n-1)/2 in an undirected graph (Scott 2000: 75).

[2] These concepts include cliques (Luce & Perry 1949), n-cliques (Alba 1973), n-clans and n-clubs (Mokken 1979), k-plexes (Seidman & Foster 1978), diplexes (Seidman 1980) blocks, n-components and unilateral components (Harary, Norman & Cartwrights 1965).

sermann & Faust 1994: 254; Scott 2000: 114). However, since such totally connected sub-groupings are quite uncommon in social life, a number of more relaxed concepts have been introduced: e.g. n-cliques, n-clans, and k-plexes.[3] Nevertheless, because of the limitations of these more relaxed constructs (see Scott 2000: 116-117), we will use the stricter graph theoretic concept of the clique. Luce & Perry (1949) and Harary (1969) define a clique as a maximal complete sub-graph. Using the graph theoretic concept of the clique as a starting point in our analysis is accepting the limitations of the strict clique concept (see Wasserman & Faust 1994 for an overview) as rather unproblematic, because a central interest of this study lies exactly in one of these critique points – the overlap of cliques.

Clique overlap, a complementary measure of network integration, can be understood as the extent to which members of a clique interrelate with members of other cliques. This can be calculated in a number of ways, e.g. by taking only one or several types of relationships into account (Kilduff & Tsai 2003: 47; Provan & Sebastian 1998: 457). One-dimensional clique overlap scrutinizes how actors are connected in a network of single dimension relations and how the substructures of their network overlap. Multi-dimensional clique overlap, by contrast, indicates how these actors are tied together in a network of more than one relational dimension – and how these relations overlap with those of other cliques.

Dividing actors of a network into sub-groups and analysing how they overlap can be an important means for understanding how the network as a whole is likely to facilitate or constrain certain actions of these actors who, in their practices, refer to and sometimes mindfully attempt to change these structures (Giddens 1984; Sydow & Windeler 1998). For example, comparing two networks where in one network two cliques are overlapping and in the other network the cohesive subgroups do not overlap, one would expect the diffusion of information, knowledge and innovation to occur more rapidly in the former, where boundary spanners function as bridges between the otherwise separate cliques (Hanneman 2001: 77). A recent study of the biotechnology sector (Owen-Smith & Powell 2004) actually indicates that membership in loosely connected but coherent network configurations conveys benefits in the generation of innovations to organizations in knowledge-intensive industries.

Innovation, that goes beyond invention and includes the development and implementation of new ideas in order to solve problems (Van de Ven 1986; Dosi 1988), is an important network- and cluster-level outcome. However, the generation of innovations in networks appears to

[3] In an n-clique n (usually n=2) is the maximum path distance at which members will be regarded as connected (Scott 2000); in an n-clan the diameter of an n-clique is limited to n (Mokken 1979), and k-plexes are sets of points in which each point is adjacent to all except k of the other points (Seidman/Foster 1978).

require substantive integration fostering the transfer of rather complex and often tacit knowledge, i.e. organizations rather are densely connected by multiplex relationships. With regard to organizational performance, however, Uzzi (1997) shows that a mixture of such embedded ties and market relationships is preferable, since while the former offer rich possibilities for exchanging even tacit, context-sensitive knowledge, the latter keep competition intact and avoid structural inertia. In addition, Von Hippel (1987) finds that innovation is enhanced by informal cooperative R&D relations that span organizations and are the medium and result of the informal exchange of information among organizations, while Rogers (1995) posits that firms with a better access to such information that might be shared in different relational dimensions are more innovative. Powell, Koput & Smith-Doerr (1996) show that in fact behind most formal (contractual) ties lies a variety of informal relations, especially between the researchers, developers, managers and other organizational members in high-tech industries. And other research even indicates that informal ties are antecedents of official ties (Gulati 1995). In his analysis of network structure and innovation, Ahuja (2000) makes a distinction between collaborative arrangements that involve a technological component on the one hand and those focussing only on sharing marketing resources on the other and finds that in inter-firm networks, increasing structural holes have a negative effect on innovation. Thus, the questions of whether actually weak or strong ties and whether bridges or structural holes are conducive to innovation activities are still heavily debated in network research (cf. Powell & Grodal 2005).

In order to shed some additional light on the relationship between the integration of relational structures and innovation as a network level outcome, in this study multi-dimensional clique overlap, that indicates how cliques of different relational dimensions overlap, is measured. However, in contrast to much of the research on innovation in networks, we do not assume a unidirectional, causal relationship between network integration and innovation or any other network-level outcome. In line with structuration theory, used here as a meta-theory (Giddens 1984; Gioia & Pitre 1990), we rather propose a recursive relationship between integration and innovation. That is, network integration may as much foster the generation and implementation of new products, services and processes in a network as innovations may impact the level and kind of network integration, by stimulating the development of common frames of reference and the adaptation of norms and/or by simply intensifying interorganizational interaction, for instance.

This discussion leads us to a proposition supplementing the one on the differences between formal network governance and actual network relationships. That is, we expect, very much in line with the findings of Provan & Sebastian (1998) in the U.S. health care industry, that as a result of considerable heterogeneity and differentiation in industry clusters, sub-networks, or cliques will be a prominent aspect of the structure of the cluster. It is these cliques, and especially, the overlap among cliques, that are presumed to carry the burden of network integration and be the focal loci and structural context of innovation activities within the cluster (Proposition 2).

Cluster Governance, Network Integration, and Innovation: Investigating a Photonics Cluster in Germany

To understand cluster micro-processes with regard to formal cluster governance, actual network integration and innovation activities, we study the emergence and overlap of organizational cliques in an optics/photonics cluster in Berlin-Brandenburg. The cluster we investigate competes and collaborates with several other photonics regions and clusters in Germany and, increasingly, on an international level. To develop this cluster, an association with a governing board was set up formally in 2000 to take part in a national competition for governmental funding. After the funding was granted in 2001, a “network administrative organization” (Human & Provan 2000) was established, whose task it is to support the board in managing the cluster and to provide a wide variety of services to the members of the association.

Because of the anticipated size and diversity of the cluster, which was originally thought to include up to 300 organizations, formal substructures were established, each representing a specific technological focus and mostly headed by a member of the board (see Table 1). The sub-clusters include (a) optical technologies for the internet (OTI), (b) uv- and x-ray technologies (UVR), (c) bio-medical optics (BioMed), and (d) traffic and space applications (OTVR). In one of these sub-clusters (UVR) a particularly networked and vigorous subset of actors emerged, the RSS network. Today, the association comprises 91 (85 in 2003) organizations, with about half of them originating in the economic sphere and about a third in the science sphere.

Inclusively symmetrized (including the potential of unreciprocated personal; strategic r&d and commercial relations)
Minimum set size of **three** (three actor clique)

Clique and Network Characteristics	OTI (communication technologies)		UVR (uv- and x-ray technologies)		RSS (x-ray analysis technologies)		BioMed (bio-medical applications)		OTVR (transportation and space)	
	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003
Network size	21	26	44	45	14	14	27	29	24	25
Network density	0,2405	0,3723	0,2563	0,3439	0,4560	0,5549	0,2208	0,3042	0,2464	0,3367
Network cohesion	0,1333	0,2954	0,1501	0,2192	0,2637	0,3846	0,1168	0,1773	0,1413	0,2200
Number of Cliques										
personal ties	11	27	107	185	12	12	21	34	30	35
R&D ties	7	14	23	44	9	13	10	28	2	10
commercial ties	2	6	26	43	3	3	9	17	4	8
Number of Actors in Cliques										
personal ties	15	21	39	44	14	14	22	25	20	22
R&D ties	9	15	24	32	12	14	14	18	4	11
commercial ties	6	12	25	31	6	6	12	18	6	12

Table 1: Clique and network characteristics of the OpTecBB technological sub-clusters in 2000 and 2003

The different knowledge and expertise held by organizations in these two distinct spheres makes interorganizational integration exceptionally important for generating innovative projects, but also particularly challenging. Though only very few of these organizations compete in product markets, many of them compete for research funding and highly-qualified personnel; this again complicates network integration. Despite this competition, within and across some of the technological focus groups cooperative inter-organizational networks have evolved over time. Within these networks, R&D projects are frequently coordinated, even amongst competitors. Thus, both collaborative and competitive elements can be identified both within and across the cluster that by now has even built a regional industrial identity.

The quantitative data used in this study were gathered in spring of 2004 for 2003 and, retrospectively, for 2000, in 81 semi-structured telephone interviews with, at that time, almost all (95.3 %) member organizations of the association. The data focus on attributes of the organizations involved in cluster activities as well as of the interorganizational relations that are thought to be an outcome as well as a medium of interorganizational interaction (Giddens 1984; Sydow & Windeler 1998). Interorganizational involvement through cliques, as indicated earlier, was measured in three relational dimensions: personal, R&D and commercial.[4]

In addition, we gathered qualitative data with the help of about seven semi-structured personal interviews with the representatives of the technological focus groups, the director of the

[4] The collected relational data of R&D- and commercial ties is further differentiated into non-existing, weak (contacts once or twice per year), medium and strong (contacts more than once a month) ties. For the analysis of cliques and clique overlap in this study we used inclusively symmetrised R&D- and commercial as well as personal ties in order to include the potential of unreciprocated personal, strategic R&D and strategic commercial relations. We decided to take this analytical step in order to account for the fact that especially in large organizations not all relations are known to the (usually) contacted director, CEO or photonics representative of a particular organization.

board, and with the CEO of the network administrative organization; analysing documents such as minutes, annual reports, master plans and roadmaps; and via participant observation of a broad array of strategy meetings, workshops and colloquia over a period of almost six years. The quantitative data have been analyzed using UCINET 6 (Borgatti, Everett & Freeman 2002); the qualitative data, so far, have been drawn on to develop a deeper understanding of the processes that brought about the formal and the actual network structures.

Measuring Cliques, Clique Overlap and Innovation in Networks and Clusters

UCINET is particularly useful for the analysis of cliques and clique overlap, because the software automatically produces a list of cliques found in a given one-dimensional network (Borgatti, Everett & Freeman 2002). In addition, it produces a clique co-membership matrix and a clustering that provides non-overlapping groups. The group co-membership matrix is the n-by-n clique overlap matrix A in which A (i,j) is the number of times that i is in a clique with j. The diagonal at the i^{th} position represents the number of cliques containing i and can be interpreted as a centrality measure of i indicating embeddedness in dense regions of a network (Everett & Borgatti 1998).

In UCINET the generated group co-membership matrix is then subject to a hierarchical clustering algorithm that generates a single-link clustering table that displays non-overlapping groups. However, the clustering exhibits three main constraints: First, it is based on dyad activity and not on the overlap of the cliques, resulting in a bias towards a large number of overlapping cliques. A second problem of the clustering is that it does not disclose any underlying clique structure of the network. Thirdly, it simply removes overlap (see Everett & Borgatti 1998 for examples). An additional constraint is that the method does not provide a means to analyze multi-dimensional overlap.

In this study of an emerging photonics cluster in Germany, one-dimensional clique overlap was computed using Provan & Sebastian's (1998) procedure of counting the number of times actors in a particular relational type of clique (personal, R&D, commercial) appeared in at least half the cliques of that type, counting only relatively high levels of one-dimensional clique overlap. Low overlap would indicate that the members of these cliques interact intensively among themselves but only little across different cliques. Whereas this might be a sign for denying clients/patients a needed service that benefits from a strongly integrated service system for mentally ill patients as in the study of Provan & Sebastian, in innovation contexts a considerably lower and higher level (than the "cut-off value" of 50% clique overlap) of clique overlap also needs to be considered.[5] For information relevant to innovation (e.g. about customer needs or a new technology) can spread using only one actor connecting two cliques. In the light of the empirical studies discussed above, this cliques over-spanning tie could be either weak or strong. Nevertheless, complex tacit knowledge is more likely to spread through well integrated network structures. Therefore a more sensitive measure, clique overlap degree, was calculated, which is simply the sum of (actor's clique co-membership minus one) divided by ((number of cliques multiplied with the number of network actors) minus the number of network actors).

The study of multi-dimensional network integration here focuses the attention on multi-dimensional clique overlap in rather multiplex networks, considering first personal, second R&D, and third commercial relationships. Thereby, multiplexity can be measured at the individual actor level and at the level of the entire network. A high degree of multiplexity of an individual actor indicates high embeddedness of the actor in a network and signifies less liability to disruption of single relationships. An actor with a large number of multiplex relations is expected to have a high potential of mobilizing different resources and information through these relations. On the other hand, such an actor is subject to a high level of social control. At the network level, the degree of multiplexity specifies the overlap between the different relation-specific networks. Multi-dimensional network integration can thus be measured as the extent to which actors are members in cliques with regard to more than one relational dimension. In order to validate the findings concerning multi-dimensional network integration, an alternative measure could be computed – identical three-dimensional overlap. For identical three-dimensional overlap, the percentage of identical cliques in all three relational dimensions is calculated.

This is done over a longer period of time, at present for the years 2000 and 2003. The application of a longitudinal study in network analysis, however, is a difficult endeavour. Firstly, it is time consuming and quite expensive to collect network data at different points in time for a number of networks. Secondly, the 'real' application of the dynamic models would be even more demanding, since they required continuous recording of network changes (Wasserman & Faust 1994: 730). We share the general assumption of Snijders (2005) that, although observing the network at a number of different time points, there is an underlying network evolution going on. But in contrast to Snijders' statistical modelling of social networks, we apply

[5] We used the second measure, one-dimensional clique overlap degree as a more sensitive verification means for the correlation analysis.

qualitative data in order to interpret the dynamics underlying this process; data that stretch well beyond the year 2003 up to the present.

Innovation in general can be measured in a number of ways. Common measures in innovation literature are the number of patents or the number of new products brought to the market by an actor or a number of cooperating actors in a given period of time (e.g. Hagedoorn & Schankenraad 1994; Shan, Walker & Kogut 1994; Stuart 2000). Even though a large number of scholars stress the usefulness of patents as a measure of innovation output of organizations (e.g. Griliches 1990) we take a more critical stance. The measure of patents is considered as rather problematic because it is more indicative of an invention rather than an innovation showing only the right of an actor to produce and market the patented product or service rather than providing direct evidence about the actual use and exploitation of the patent. Moreover, there are often significant time-lags between inventing, patenting and marketing a product or service that are difficult to deal with in empirical research. Further, quite a number of innovations are not patented at all in order to keep the innovation secret and firms overall differ in their tendency to patent their innovations (Cohen & Levin 1989; Griliches 1990). The actual number of new products or services brought to the market, however, has its limitations as well. For instance, these may exhibit no or different degrees of innovativeness.

In this study we apply a collection of measures in order to make the measurement of innovation activities more robust. We developed a network level innovation index (NLII) that contains (1) the number of cooperative innovation projects as perceived by the members of OpTecBB in 2003; (2) the number of cooperative projects by OpTecBB members competing for public funding as officially registered by the network administrative organization; (3) the perceptions of experts on the innovativeness of networks; (4) experts' perceptions on innovation activities within the photonics cluster in the Berlin-Brandenburg region.

Data for measures (1) and (2) were collected during the telephone interviews in our survey and checked against annual reports of research organizations and publicly quoted companies as well as against documents and perceptions of members of the network administrative organization. Data on experts' perceptions on network innovativeness (3) and innovation activities (4) were collected in a survey conducted among the members of the board in the first quarter of 2006. The members of the board were interviewed by one of the authors during a board meeting. The questionnaire included seven point Likert scales and involved questions concerning the perception of the innovation success, cooperative innovation activities, openness of the exchange of information in innovation activities, the utilization of regional competencies in innovation activities, and the effectiveness in the generation of innovations in the relevant networks for the year 2003. Prior to conducting the survey we checked the items with the network administrative organization for relevance.

In order to generate a simple ranking measure of network innovativeness that would include different measures, we z-standardized each measure to eliminate the distances within each measure producing a comparable standardized deviation measure from the average. Regardless of some disparity, the overall patterns of results were alike. That is, the scores for the one sub-cluster (OTVR) are by far the lowest and consistently below average. All scores for a part of another sub-cluster (RSS) are above average, and for all the other sub-clusters (OTI[6], Bio-Med, and UVR) the scores are somewhat inconsistent. Then the average score of the four scores generated for each network was constituted to create a single mean score for each network – the NLII – reflecting the overall network innovativeness (see Table 2).

Sub-cluster / Measures of innovation activities	OTI (communication technologies)	UVR (uv- and x-ray technologies)	RSS[7] (only x-ray analysis)	BioMed (bio-medical applications)	OTVR (transportation and space)
(1) product innovation projects	18	29	20	25	4
z-standardized (μ=19.20; δ=8.52)	-0.14	1.15	0.09	0.68	-1.78
2) cooperative projects applied for public funding (state)	*	*	*	*	*
z-standardized (μ=*; δ=*)[8]	-1.17	1.26	0.29	0.78	-1.17
(3) experts' network innovativeness perceptions	4.71	4.26	4.83	3.86	3.86
z-standardized (μ=4.30; δ=0.41)	0.99	-0.11	1.28	-1.08	-1.08
4) experts' innovation activity perceptions	4.84	4.90	5.30	3.53	4.10
z-standardized (μ=4.53; δ=0.63)	0.48	0.58	1.21	-1.58	-0.68
network level innovation index (NLII)	**0.04**	**0.72**	**0.72**	**-0.30**	**-1.18**

Table 2: Network innovation of OpTecBB technological sub-groups in 2003

6 The low scores of the OTI projects in 2003 might be attributable to the aftermath of the telecom crisis down turn in 2000/2001.

7 RSS is a sub-network within the "official" UVR network that emerged over the last five years. Within RSS most of the collaborative innovation activity in this particular technological group is taking place.

8 *) Not stated to guarantee confidentiality.

Research Findings: Formal Governance, Actual Cliques, Clique Overlap and Innovation Activities

Formal Governance and Actual Cliques. During the formation phase of OpTecBB, the four technological focus groups mentioned were already set up, each led by a spokesman and his/her deputy that, as a dyad, systematically represent the science as well as the economics sphere. These focus groups or sub-clusters, that do not form a legal entity on their own, were intended to include a critical mass of actors in their technological specialization from these two spheres and to provide the social context in the attempt to network along the value chain and to generate innovative products. Over the last five years the spokesman in general, and sometimes also the deputy, was also a member of the board of OpTecBB e.V. – the formal association. Despite this hierarchy-like linkage, the focus groups or sub-clusters organize their activities relatively autonomously. The relationship between the board of the association and the network administrative organization, that is part of the legal entity (e.V.), is also hierarchical, i.e. the CEO of the network administrative organizations reports to the board. Though the network administrative organization has been – and still is – very important for the development of the cluster and the sub-clusters, it has been less influential if compared to the dyads heading the four sub-clusters and should not be considered as a source for homogeneity or isomorphism in the cluster.

The official OpTecBB substructures have been a constitutive property of the formal cluster governance for the last five years and are only now being reconsidered and a major reorganization is just beginning to be implemented. This is in part due to the fact that technologically focused collaborative groups (especially in the fields of x-ray analysis, laser material processing, photonic components and lighting technologies) existed or emerged over the last five years (since the implementation of the OpTecBB substructures) that were not represented by the official network governance. Further, since approximately 2003, organizations within the technologically focused networks increasingly began to explore interdisciplinary opportunities, resulting in a growing number of collaborative activities across the technological focus groups.

In the course of studying the development of the cluster over a period of more than five years, it became clear that two of these four formal sub-groups are integrated quite well, while the others are not. Qualitative indicators for this are the stability and effectiveness of the leadership dyad of the sub-cluster, the frequency and intensity of sub-cluster meetings, the formation of a cohesive group of small and larger corporations and research organizations, involving actors from both spheres, the number and complexity of collaborative projects initiated, the agreed upon narrow focus of the involved actors on a particular technology, as well as the perceptions of the actors involved. Quantitative indicators are differences in density scores and clique measures. The innovativeness of the networks is compared with regard to the NLII.

The well-functioning sub-clusters are UVR and OTI. As mentioned earlier, within the official UVR sub-cluster an even more technologically focused and densely interrelated group of firms and research organizations emerged, the RSS network. Within the OTI network, a number of organizations from both spheres also organized a considerable amount and variety of collaborative innovation activities at the network level. They met more frequently and engaged more intensively in innovation activities. This (qualitative) assessment is supported by the higher level of interorganizational interaction that is reflected in the greater density scores and the more pronounced cliques in these two sub-clusters (see Table 3)[9]

In order to generate the integration measure (3 dimensional average clique membership) for each sub-cluster in the lower part of Table 3, first the percentage of the sub-cluster organizations that were involved in cliques in each relation was calculated. The score represents the average over the three relations. Whereas the three actor clique investigation yields mixed results, especially concerning OTI and BioMed, the much more strict exploration of four actor cliques (higher level of integration) indicates higher levels of interrelation and interaction among the members of OTI, UVR and especially RSS in all three relational dimensions.

Sub-cluster / Measures of integration	OTI (communication technologies)	UVR (uv- and x-ray technologies)	RSS (only x-ray analysis)	BioMed (bio-medical applications)	OTVR (transportation and space)
Density in %	37.23	34.39	55.49	30.42	33.67
3D average clique membership in **three** actor cliques in %	61.6	79.3	80.9	70.1	60.0
3D average clique membership in **four** actor cliques in %	44.9	56.3	69.1	34.5	36.0

Table 3: Network integration measures of the OpTecBB sub-clusters in 2003

In contrast, the BioMed and OTVR sub-clusters did not live up to expectations. The BioMed group, though quite strong in the generation of collaborative projects, and despite formally

9 Density scores of the sub-cluster can be interpreted as the higher level of network integration of OTI, UVR and RSS even though UVR (45) is considerably larger and RSS (14) much smaller than the other sub-clusters (average 27).

also having institutionalized the dyadic leadership structure[10], never established a working structure and failed to stimulate the exchange of knowledge between the actors organized within OpTecBB. However, knowledge transfer was often realized on a bilateral basis between firms and research organizations (or clinics) and fostered by the state-supported biotech and medical technologies clusters in Berlin. Finally, the OTVR network may principally lack a critical mass of photonics organizations in the technological field of transportation and space applications resulting in few collaborative innovative activities and outcomes within OpTecBB.

In sum, this provides empirical evidence for our Proposition 1 that, despite a rather homogenous formal cluster governance, quite heterogeneous substructures – networks – have emerged within the cluster.

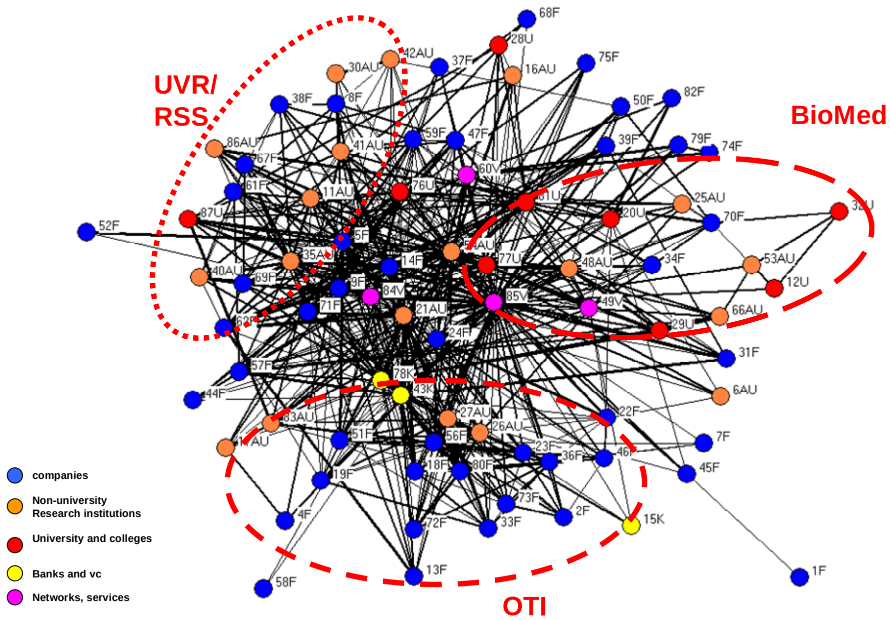

Figure 1: OpTecBB network structure in 2003 and identifiable sub-clusters

Looking at the overall network structure of OpTecBB in 2003 (reciprocated relations) supports this diagnosis, for NetDraw software applied here (see Figure 1) groups actors closest if they exhibit low path distances to one another. In fact, Figure 1 illustrates that organizations within the official structures of OTI and UVR (including RSS) can be identified within the larger and complex connected OpTecBB network as closely co-located actors. BioMed actors, even though they do not organize their innovation activities within OpTecBB, can also be recognized as an interrelated group (this is due to the fact that the relational data were col-

[10] In the course of six years since the formation of the BioMed sub-cluster, three different dyad constellations were already implemented. In the other sub-clusters, this dyad has been much more stable – in most cases the spokesmen and their deputy spokesmen are still the first “cast”.

lected independently from OpTecBB-activities). However, the fourth network, OTVR, cannot be identified as a coherent group within the cluster.

Network Integration, Clique Overlap and Innovation Activities. The network density scores can also be used for establishing the level of network integration, at least as a starting point. Density scores were measured using all three relational dimensions. BioMed, the medium innovative sub-cluster as measured by the NLII, displayed the lowest general sub-cluster integration (30.42%) followed by OTVR (33.67%) the least innovative sub-cluster. The largest and most innovative sub-cluster, UVR (34.39%), the medium innovative sub-cluster OTI (37.23%) and RSS (55.49%), that is part of the UVR sub-cluster, exhibit higher density scores. These findings are generally supported by the stricter cohesion measure of the sub-clusters (see Table 3 for details). These results indicate that the more densely connected sub-clusters, as measured by network density scores, exhibit higher ratings in the NLII what seems to support the assumption that integrated networks are more innovative than less integrated ones and/or that the innovative sub-clusters reproduce more densely connected relational structures.

In the analysis of overlapping cliques, we first had to decide on their size. Since there is no research reported in the literature, we based our decision on the available data. As in the study conducted by Provan & Sebastian (1998), an assumption in the present analysis is that greater and more intensive integration within and across cliques would be more effective in terms of innovation (activities). In a first step we determined the clique size in all three dimensions that could be compared across the different sub-clusters and at the two points in time. We began by generating lists of three, four, and so on actor cliques in all five networks. But already the four actor cliques did not yield the possibility to compare cliques and clique overlap in all dimensions, in all networks and at the two points in time. Therefore we concentrated our analysis on three actor cliques, even though there are larger cliques present in the networks (especially in OTI, UVR and RSS).

Table 1 represents the findings concerning the number of cliques and the number of organizations in cliques, not considering overlap. One first discovery is that across the sub-clusters in this field the personal networks seem to be integrated to the highest degree, measured by the number of actors in cliques and the number of cliques, indicating something like a cluster atmosphere in which actors know each another and share information concerning their industry in the region. The networks in the commercial relation, on the other side, exhibit the lowest scores. This finding is in line with the fact that photonics companies in Berlin-Brandenburg conduct the largest proportion of their business outside the region. Anyhow, photonics companies in the region are still significantly more focused on research and development in their collaborative activities than on commercializing their products and services.

In more detail, UVR had a very high score of personal cliques and relatively numerous R&D and commercial cliques. This is due in part to the fact that UVR is simply the largest sub-cluster and that UVR-technologies have a very long tradition in this region. BioMed also had a relatively high number of cliques in all three relational dimensions. This may reflect the fact that a number of innovation activities are going on in this sub-cluster on a rather isolated tri-lateral level, but not in densely interrelated webs. This interpretation is supported by the fact that only a considerably lower number of four actor cliques can be found in this sub-cluster. OTVR, OTI and even RSS, the latter being the intensively networked part of UVR, have low clique counts in the commercial relational dimension. This finding, as well as the number of actors in cliques in a specific relational dimension, is not conclusive with regard to the level of innovation in the networks. However, looking at the four actor clique results with respect to the other relational dimensions reveals that OTI and RSS are rather integrated in the R&D dimension and OTVR even exhibits a small number of four actor cliques in the commercial dimension and none in the R&D dimension. At this level of analysis, the results are mixed and do not deliver strong evidence that greater and more intensive integration facilitates innovation output or that rather innovative activities in sub-clusters cause high levels of network integration. Furthermore, these results did not consider integration across cliques.

As stated earlier, we calculated one-dimensional clique overlap for each type of relation as the extent to which organizations appear in at least half the cliques of that type. Although the absolute number of organizations in overlapping cliques is rather small, the relative scores for one-dimensional clique overlap (as displayed in Table 4) specify higher levels of clique overlap in all three dimensions especially in the RSS network and the OTI sub-cluster. UVR, BioMed and OTVR exhibit low overlap in almost all relational dimensions meaning that the members of cliques tend to interact amongst themselves but not across cliques. This general picture is supported by the alternative measure of clique overlap degree.

Inclusively symmetrized (including the potential of unreciprocated personal; strategic r&d and commercial relations)
Minimum set size of **three** (three actor clique)

Clique and Network Characteristics	OTI (communication technologies)		UVR (uv- and x-ray technologies)		RSS (x-ray analysis technologies)		BioMed (bio-medical applications)		OTVR (transportation and space)	
	2000	2003	2000	2003	2000	2003	2000	2003	2000	2003
Clique Overlap (one dimensional)*)										
personal	1/15= 0,067	2/21= 0,095	1/39= 0,026	1/44= 0,023	2/14= 0,143	2/14= 0,143	2/22= 0,091	3/25= 0,120	0/20= 0,000	1/22= 0,045
personal clique overlap degree**)	0,133	0,185	0,115	0,118	0,273	0,312	0,106	0,119	0,138	0,158
research and development	2/9= 0,222	2/15= 0,133	0/24= 0,000	0/32= 0,000	3/12= 0,250	3/14= 0,214	1/14= 0,071	0/18= 0,000	2/4= 0,500	1/11= 0,091
r&d clique overlap degree**)	0,095	0,104	0,057	0,064	0,188	0,232	0,078	0,087	0,083	0,084
commercial ties	0/6= 0,000	3/12= 0,250	1/25= 0,040	1/31= 0,032	4/6= 0,667	4/6= 0,667	1/12= 0,083	1/18= 0,056	2/6= 0,333	1/12= 0,083
commercial clique overlap degree**)	0,000	0,054	0,055	0,059	0,179	0,143	0,069	0,071	0,083	0,097
Multi Dimensional Overlap										
Multiplexity (3D)***)	3/6= 0,50	8/12= 0,67	18/24= 0,75	26/31= 0,84	6/6= 1,00	6/6= 1,00	6/12= 0,50	14/18= 0,78	0/4= 0,00	7/11= 0,64
Identical Overlap (3D)****)	1/2= 0,50	3/6= 0,50	3/23= 0,13	5/43= 0,12	1/3= 0,33	1/3= 0,33	0/9= 0,00	0/17= 0,00	0/2= 0,00	1/8= 0,13

*) Clique Overlap (one dimensional) is defined here: number of organizations that are member in half or more than half the number of cliques divided by the "number of organizationa in cliques"
**) sum of (organizationa's clique co-memberships-1) divided by ((number of cliques multiplied with number of network organizations) minius number of network organizationa)
***) percentage of organizationa that were members in cliques in all three relational dimensions
****) percentage of identical cliques in all three relational dimensions

Table 4: (Multi-dimensional) clique overlap in OpTecBB' sub-clusters

Furthermore there appears to be a correlation between the overlap of cliques in the three analyzed relational dimensions in the networks studied and innovativeness of networks (see Appendix I). The Pearson correlation coefficient in all three cases is positive: for personal clique overlap there is a medium correlation (r=0.214); for R&D clique overlap a weak correlation (r=0.181) could be found; and for commercial relational clique overlap a medium correlation (r=0.474) was calculated. This finding is in general supported by the alternative clique overlap degree measure. However, due to the low absolute numbers of organizations present in these overlapping cliques, this finding does not appear to be very robust.

The examination of multi-dimensional clique overlap or multiplexity focuses the attention on the extent to which organizations in a personal clique, for example, were also members of a R&D and a commercial clique. Sub-clusters with a noteworthy multi-dimensional clique overlap would have a core group of organizations that were heavily integrated and involved with one another in multiple ways (Provan & Sebastian 1998), which would be essential for the generation of innovation. On the other hand, innovation activities would contribute to the initiation and reproduction of relations between organizations in multiple dimensions.

In absolute terms there are a larger number of organizations that are members in cliques of all three dimensions in all sub-clusters. The lower part of Table 4 shows the multi-dimensional clique overlap scores for the OpTecBB sub-clusters. The muliplexity (3D) score for OTVR, the lowest innovative ranked sub-cluster, for example, represents the fact that seven of the eleven organizations (64%) involved in OTVR's R&D cliques were also members in the personal and the commercial cliques. OTI, the average innovative rated sub-cluster, had the second lowest overlap (67%) followed by BioMed (78%), the slightly below average ranked sub-cluster. UVR and RSS, the sub-cluster and network that exhibit the highest average innovation scores in Table 2, also have the highest percentage of organizations that were members in all three relational dimensions (84% and 100% respectively). These findings indicate that there is a core of organizations in all the sub-clusters that are integrated and involved with one another in a multiplex way. Further analysis indicates a strong correlation between multi-dimensional clique overlap and innovativeness of networks, measured as multiplex 3D overlap (r=0.789). The alternative measure of identical overlap shows a medium correlation (r=0.305) between the two variables (see Appendix I).

In sum, all this provides enough evidence for our Proposition 2, i.e. the close association between cliques and clique overlaps as indicators of the level of network integration on the one hand and the overall level of network innovation activities on the other, though – in face of the meta-theoretical consideration – we do not assume an unidirectional, but rather a recursive relationship between network integration and innovation.

Dynamics of One- and Multi-dimensional Network Integration. Comparing the general network integration scores of 2003 with those of 2000, the year before the cluster initiative even started, reveals that in all sub-clusters the number of relations (as measured in density scores) as well as the level of integration (as measured in the form of the number of cliques and actors in cliques) in most instances increased in all relational dimensions; at the very least, they stayed the same. The general picture that the sub-clusters were more integrated in the personal dimension and the least integrated in the commercial dimension can be also found in the 2000 data. Nevertheless, the general level of network integration increased between 2000 and 2003.

A cautious look at the *one-dimensional* clique overlap (because of the low numbers of organizations that are members in half or more than half the number of cliques = clique overlap actors) seems to support this finding at first sight, but a closer analysis reveals that the results are actually mixed: On the one hand, the relative clique overlap measure decreases in cases when the absolute number of clique overlap actors stays the same and the number of actors involved in cliques of that type increased between 2000 and 2003 (as in the case of R&D in RSS; R&D in OTI; commercial in BioMed). On the other hand and considering a second possibility of decreasing clique overlap measure, the absolute number of clique overlap actors decreases (as in the case of R&D and commercial in OTVR).

Results are clearer and more robust when considering *multi-dimensional* clique overlap. In all sub-clusters, the absolute as well as the relative counts for the two alternative measures are higher in 2003 (or at least stayed the same), indicating, as to be expected after more than five years of systematic cluster building, a generally higher-integrated and increasingly multiplex network if compared to 2000. Since innovation output measures were not available for 2000, the data analysis was limited and no firm conclusions can be drawn with respect to changes of overall network innovativeness.

Summary and Conclusions

While the involvement in a cluster of firms operating within the same industry may actually be conducive to the innovativeness of firms within the cluster, it is unclear how research institutes, customers and suppliers of products and services, as well as associated institutions really interact with each other in a cluster. In order to understand the micro-structures and -processes at work in such systems we studied an emerging optics/photonics cluster in Germany that currently comprises more than 90 organizations from the economic and science spheres in particular, using a quantitative and a qualitative research methodology.

In this paper we focus primarily on the role of cliques and clique overlaps because this allows us to detect the actual networks in clusters, to gain information about the level of network integration, and to relate it to innovation activities. Given the size, diversity and interdisciplinarity of the cluster studied, firstly we expected that, despite a formal governance structure trying to produce some homogeneity, the networks of relationships – considered as an outcome of actual practices and measured by cliques and clique overlaps – would be quite dissimilar. While the formal governance structure was described in terms of the legal set-up, the installation of four sub-clusters and some additional formal rules, the actual network relationships were measured by cliques and clique overlaps. Secondly, we proposed that not only network effectiveness in general, as shown by Provan & Sebastian (1998) for the U.S. health care industry, but network level innovativeness (as measured by a specially developed index) owes far less to integration across a network as a whole than to ties among a few organizations that provide the bulk of relationships. It is these cliques, and especially the overlap among cliques, that are presumed to carry the burden of network integration and provide the focal loci and structural context of innovation activities within the cluster.

Using quantitative data from telephone interviews with 81 of the cluster organizations for the years 2003 and, in retrospect, for 2000 (i.e. before the cluster development process was started), the analysis of the cluster cliques and clique overlaps, in addition to the more conventional density scores, confirms the two propositions: While two of the formal sub-clusters, including a specific network (RSS) operating within one of these two, turned out to be quite densely networked and exhibit more pronounced cliques and clique overlaps (which is most obvious in the case of four actor and three actor multi-dimensional cliques, respectively), the other two show a significantly lesser degree of (sub-) network integration. This is particularly true with regard to the network of personal relationships and respective cliques, indicating a kind of (sub-) cluster atmosphere in which actors know each other and share information concerning their industry in the region. Overall, the level of network integration within the four sub-clusters turned out to be considerably higher than that across the sub-clusters – despite the formal governance structure embracing all four sub-clusters and aiming at establishing across-cluster interaction as well. Nevertheless, this evidence corroborates the finding of Provan & Sebastian (1998) that multiplex and overlapping cliques provide a fair amount of network integration – and thus the social context for turning research knowledge into marketable products.

Insights from a broad array of qualitative methodologies (including semi-structured interviews, document analysis, and participant observation of strategy meetings) makes us believe that the differences found between the sub-clusters, in the main, reflect differences in sustained sub-cluster leadership, the diverse level of activities in the sub-clusters (e.g. organizing meetings, exchanging knowledge beyond bilateral relations, and collaborating in multi-lateral projects), and – in the case of one sub-cluster – even a lack of a critical mass of organizations. This finding, together with the lower degrees of one- and multi-dimensional clique overlaps, corresponds to the fact that two of the four sub-clusters (RSS included) turned out to be more innovative than the others. However, due to meta-theoretical considerations we do not assume a unidirectional causal but rather a recursive relationship between network integration on the one hand and these different levels of network level innovation on the other.

The dynamics of the actual networks of relationship show that between the years 2000 and 2003 the level of network integration increased considerably, again with regard to general network density (and in particular to personal network relationships) as well as with respect to multi-dimensional network integration. The higher level of network integration and especially increased multiplexity comes as no surprise after fairly systematic attempts to develop the cluster in general and the networks of interorganizational relationships in particular. A second round of data gathering, focusing on the networks relationships in 2005, is just under way and will surely give us more insights into these dynamics.

Because of these findings we are tempted to conclude that network integration is important for network level innovativeness. However, this integration does not necessarily have to stretch across the cluster as a whole but may be ensured by different cliques and by certain organizations that bridge the cliques. Formal governance structures can certainly help to initiate and to coordinate the development of networks of relationships but cannot guarantee a homogeneous, coherent cluster evolution, i.e. that (inter-) action is widespread in the system. Nevertheless, the identification of cliques and clique overlap in clusters is valuable to network managers since they may serve as a *leitbild* for developing (other parts of) the cluster.

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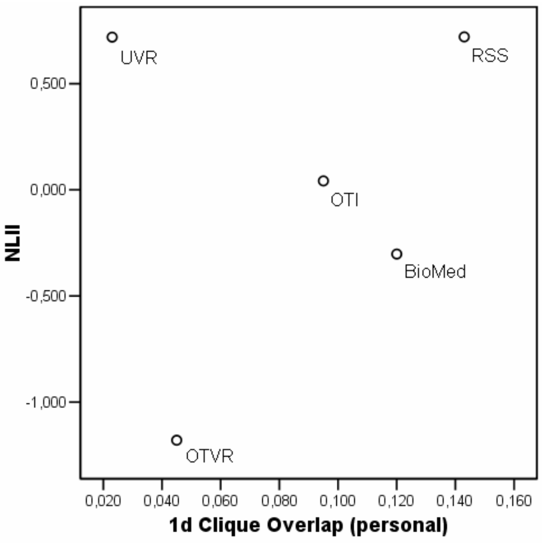
Appendix I



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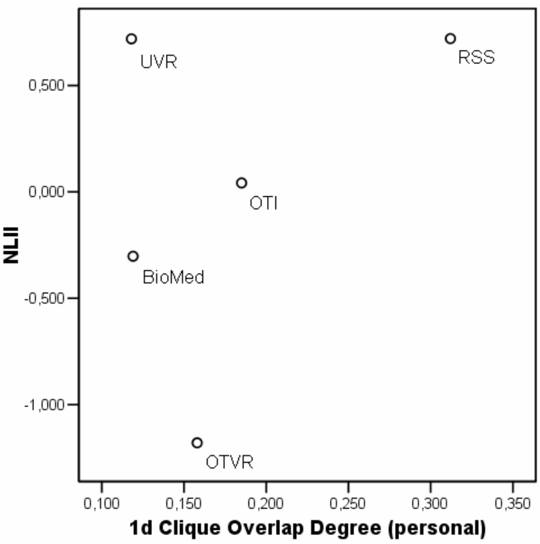

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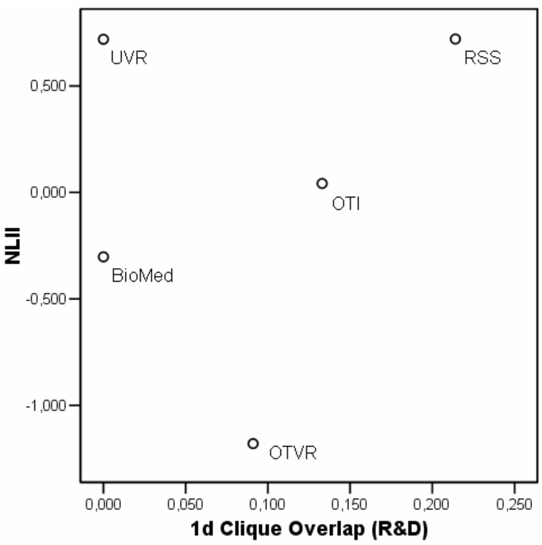

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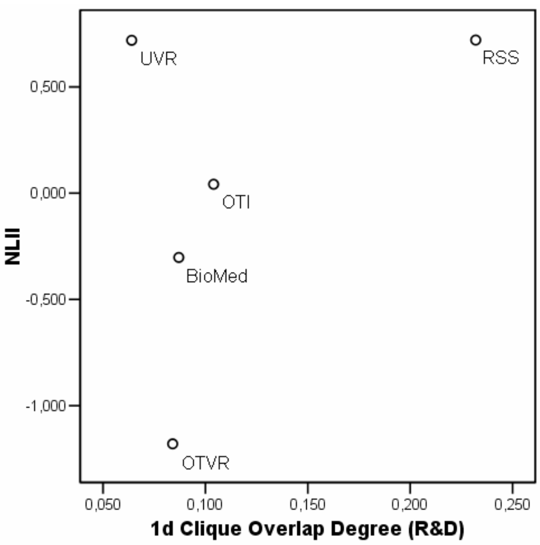

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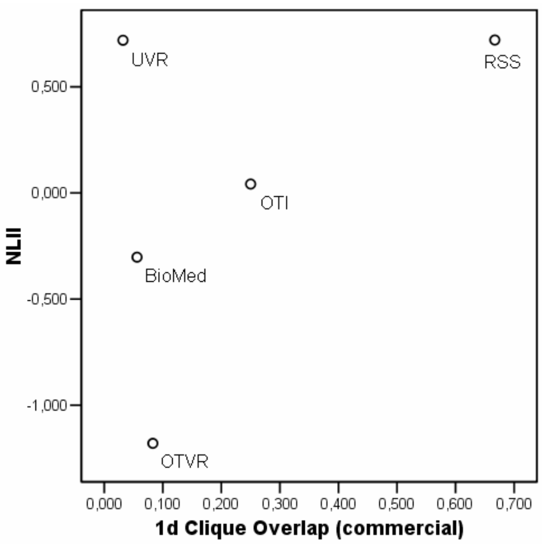

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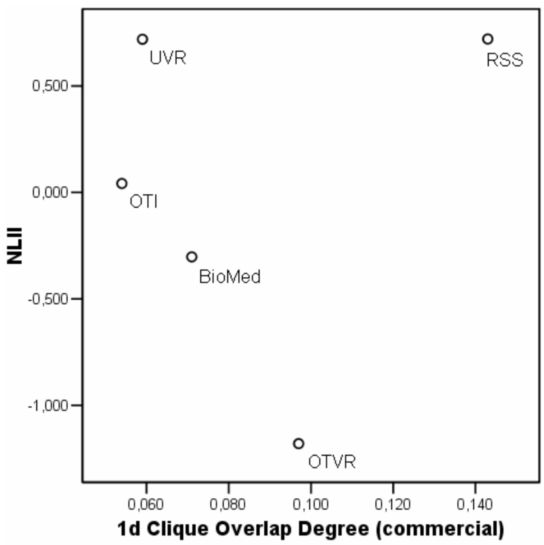

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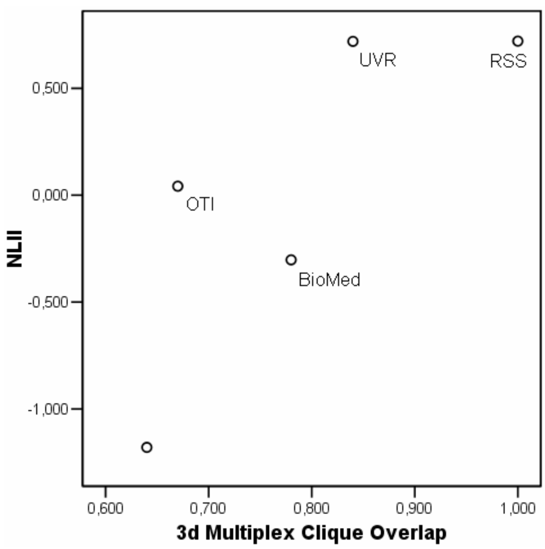

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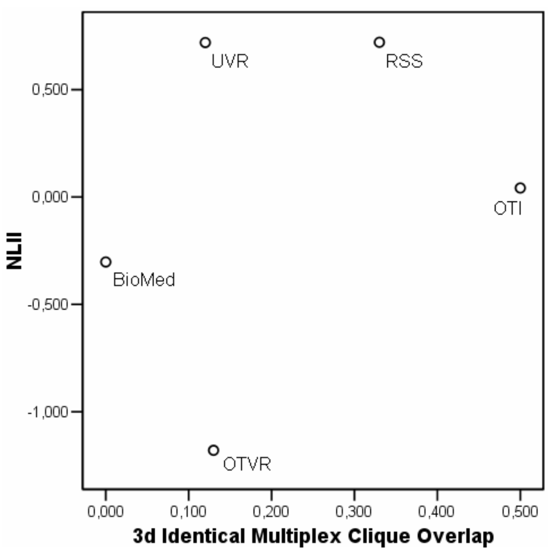

r= 0,305