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# JENA ECONOMIC RESEARCH PAPERS



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## **Interaction Structures in Local Innovation Systems**

**by**

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# Interaction Structures in Local Innovation Systems

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## Abstract

The flow of knowledge through interaction between innovative actors is central to the systemic view of innovation. We review the literature on interaction and innovator networks with a focus on regional aspects. To illustrate the relevance of these relations, we apply social network analysis methods to describe the evolution of the innovator network of Jena, Germany in the period from 1995 to 2001. During this period, the network is characterised by growth in the number of patents, actors and relations, with central positions of public research. The evolution is directed towards an increasing focus on core competencies of the network.

**Keywords:** Innovator Networks; Innovation System; R&D Cooperation; Mobility

**JEL Classification:** O31; L14; R11

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## 1 Introduction

Innovation and technological progress are fundamental to economic growth. The question regarding the essential determinants of successful innovation is at the center of research on innovation in economics. A key concept to answer this question is the systems of innovation approach (SI).

The SI approach is largely based on the idea that abilities and incentives of firms and individuals to innovate cannot be analysed in isolation. On the contrary, they are embedded within a more or less broadly defined system of actors and institutions. The diffusion of new information and knowledge is accelerated by the exchange of knowledge and experiences between the actors within the system. Thereby knowledge is accumulated and capabilities are broadened, which, if economically useful, might lead to more innovation.

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The notion of an *innovation system* integrates this systemic and interaction-based view of processes that generate novelty. Properties of and mechanisms within innovation systems are identified on several levels of aggregation. Concepts of regional or local innovation systems (see [Braczyk et al., 1998](#); [Breschi and Lissoni, 2001](#)) assume a higher propensity of interaction between individuals that are close in geographical space. Cognitive proximity, on the other hand, might be higher between individuals working on similar problems with similar methods within technological or sectoral systems ([Carlsson and Stankiewicz, 1991](#); [Carlsson, 1995](#); [Nelson and Mowery, 1999](#); [Malerba, 2002](#)). Both views are present in the literature on national innovation systems, which is more focussed on institutional and political aspects ([Lundvall, 1992](#); [Nelson, 1993](#)).

Relating the work on national innovation systems to regional economics, a vast and growing literature on regional innovation systems (RIS) emerged during the last two decades. Two facts provide the rationale for studying innovation on a regional level (see [Asheim and Gertler, 2004](#)):

1. Innovative activity is neither uniformly nor randomly distributed across geographical space. In particular, the more knowledge-intensive the economic activity, the more geographically clustered it tends to be.
2. The tendency towards spatial concentration has been increasing over time ([Leyshon and Thrift, 1997](#); [Feldman, 2001](#)). These observations contradict the view that the merits of information and communication technologies will lead to the dispersal of innovative activity over time.

The argument that geographical or spatial proximity of actors in such a system is beneficial to the establishment of relationships and the subsequent exchange of know-how and information is at the heart of this research. Also, other factors relevant to the exchange of knowledge such as technological proximity, culture, language, or institutional arrangements are frequently put forward. The prime example of a regional innovation system is Silicon Valley, a birthplace of modern information and communication technology ([Saxenian, 1994](#)). Silicon Valley today is a large agglomeration of high-technology firms that emerged in a self-organising manner in the desert of California. The success story of Silicon Valley has led politicians to foster and support such systems. While there are some examples of the success of

such policies, such as the ‘Wissenschaftsstadt Ulm’ or the BioRegio contest in Germany (Boucke et al., 1994; Dohse, 2000), there are also negative examples of such political efforts, especially in those cases where planned science parks have failed to develop innovative networks of cooperation and interactive learning (Asheim and Cooke, 1998; Asheim and Gertler, 2004). Cooke (2001) notes that, ‘a lack of systemic network development’ is observed, and, ‘these [government research laboratories] stood like cathedrals in the desert, often in agglomeration but not clustering and not creating synergies through spin-off and subcontracting activities’ (Cooke, 2001, p. 950). The problems of planning such a complex system are also highlighted by Edquist (2004, p. 191) in the following quotation:

The systematic approach to SIs suggested here does not imply that they are or can be consciously designed or planned. On the contrary, just as innovation processes are evolutionary, SIs evolve over time in a largely unplanned manner. Even if we knew all the determinants of innovations processes in detail (which we certainly do not now, and perhaps never will), we would not be able to control them and design or ‘build’ SIs on the basis of this knowledge. Centralised control over SIs is impossible and innovation policy can only influence the spontaneous development of SIs to a limited extent.

For that, the central question one has to ask in judging SIs is whether the actors are sufficiently connected to ensure collective flows of information and knowledge. During the last years, the literature on structures, properties, and functions of such networks emerged within the realm of economics, both from a theoretical and an empirical perspective. Our goal here is to present an overview of this literature and provide an empirical application of these ideas in an analysis of the innovator network in Jena, Germany.

The paper proceeds as follows. In the next section, we discuss the theoretical foundations, concepts and structure of local innovation systems. In section 3, we give a short introduction to the methodology and the data used for the empirical analysis. In section 4 we apply social network analysis methods and visualizations to describe the evolution of the innovator network of Jena in the period from 1995 to 2001. We analyse the evolution of the network more deeply in section 5, where we distinguish between network relations of entering and exiting actors to actors that are permanent members of the network. Finally, section 6 concludes the paper by summarizing and pointing towards further research required.

## 2 Innovator networks in space

An innovation system might be defined as a network of actors who interact in the processes of the generation, diffusion, and utilization of new, economically useful knowledge under a distinct institutional framework (Cantner and Graf, 2003). Institutions are understood as ‘sets of common habits, norms, routines, established practices, rules or laws that regulate the relations and interactions between individuals, groups and organizations’ (Edquist and Johnson, 1997, p. 46). Thus, an innovation system is a group of actors who are related by know-how flows subject to the institutional environment. These linkages can be built on purpose or emerge unintendedly; they can be incorporated in materials, products or persons or they can develop disembodiedly through informal knowledge exchange between the actors. Regarding the geographical dimension of such an innovation system, there is no well established definition of neither a local nor a regional innovation system. The problem is that the concept of a region itself is not clear. The scales at which regions are analysed range from the Canadian provinces of Quebec (Latouche, 1998) or Ontario (Gertler and Wolfe, 2004) to industrial districts below the urban level of aggregation (Asheim and Isaksen, 2002). It makes a difference if the state level in the US or the level of ‘Bundesländer’ in Germany is analysed in contrast to a city, or a region on the NUTS 3 level.<sup>1</sup> Therefore, we use the term *regional innovation system* for the larger entities, which usually have more political power, and *local innovation system*, whenever cities or rural areas on the NUTS 3 level are analysed.<sup>2</sup> Either way, Edquist (2004) points out that no system – on which level whatsoever – has a clear cut boundary, where there is no interaction with the outside of that system. Consequently, the definition of the boundary in an empirical study depends upon the question one asks. In the following, we concentrate on interactions between actors directly involved in the innovation process (firms, universities, public research institutes) and abstract from institutional aspects and political actors.

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<sup>1</sup>NUTS stands for ‘Nomenclature of Statistical Territorial Units’ and is the official division of the EU for regional statistics.

<sup>2</sup>Cooke (2001, p. 953) defines the region within the RIS approach as ‘a meso-level political unit set between the national or federal and local levels of government that might have some cultural or historical homogeneity but which at least had some statutory powers to intervene and support economic development, particularly innovation.’ We interpret this definition as excluding local levels, which are then termed *local innovation systems*.

## 2.1 Innovation and the region

Applications of the innovation system approach to geographically bounded entities is based on two central findings: (1) there exist regional effects in knowledge transfer, i.e. knowledge spillovers are geographically bounded;; (2) Innovation processes are to be understood as interactive and socially embedded networking activities.

Knowledge spillovers refer to the fact that actors might benefit from knowledge generated elsewhere. Spillovers are measured by estimating the influence of R&D by some actors on the productivity of another actor. While the existence of such spillovers has been proven in a number of studies ([Griliches, 1992](#)), that does not say anything about how actors benefit from them. A major step in that direction was accomplished by [Jaffe et al. \(1993\)](#), who show that knowledge spillovers are geographically bounded.

Does that mean that knowledge is a public good that is freely available for anyone? The answer provided by [Nelson \(1990\)](#) is ambiguous as he speaks of technological knowledge as a latent public good: know-how is only transferrable if the imitator also expends resources. In the case of tacit technological know-how ([Polany, 1967](#)), i.e. know-how which is tied to a specific person and its talents and cannot be articulated, it can even be considered as a pure private good. Empirical studies about firms' means to appropriate the returns from R&D support this view. Based on results from the Yale Survey, [Levin et al. \(1987\)](#) show that besides patent protection, secrecy, learning curve effects, lead time, and sales or service efforts are more effective means of appropriating profits. Based on a closely related survey conducted in 1994 among manufacturing firms, [Cohen et al. \(2000\)](#) confirm these results. Compared to the earlier results patents increased in importance. However, they are not the major mechanism in most industries, while secrecy has increased dramatically. These findings indicate that imitation is not as easy as suggested by theory. Consequently, technological knowledge cannot be classified as a pure public good. This argument is also supported by studies on the efforts of imitators to absorb the knowledge generated by the innovator. [Mansfield et al. \(1981\)](#) show that imitating costs are at least 50% of the original investment in R&D and sometimes even lie above 100%. Imitators need to dedicate resources – R&D expenditures, time – to absorb and understand the new knowledge. [Cohen and Levinthal \(1990\)](#) introduce the notion of absorptive capacity, which is a function of its level of prior

related knowledge. They characterise firms' capabilities as historical- and path-dependent, greatly influencing firms' ability to innovate themselves but also to adopt novelties.

Another important question is related to the factors influencing the generation of knowledge. Incentives are surely necessary, but potential innovators also need the capabilities and the know-how to accomplish these innovations, i.e. they have to learn by investment and external knowledge sourcing. Innovations build on previously existing knowledge and are often 'constructed' through the combination or recombination of different knowledge and know-how components (Cantner and Graf, 2003).

In this sense, the generation of technological know-how is to be seen as a cumulative learning process that essentially consists of two elements: within the idiosyncratic part each creative actor learns from his own experiences and accumulated knowledge. The second part takes the form of an outward orientation where the actors learn through communication with other actors and their experiences (Lundvall and Johnson, 1994). Technological spillovers are then the knowledge flows between actors that lead to cross-fertilisation effects in contrast to sheer imitation which might diminish the economic rents of the sending actor (Cantner and Graf, 2003).

Consequently, the sources of innovation are often found rather between firms, universities, research laboratories, suppliers, and customers than inside them (Powell, 1990). Firms engage in cooperation not only to share the costs and risks of research activities but also to obtain access to new markets and technologies and make use of complementary skills (Kogut, 1989; Hagedoorn, 1993; Eisenhardt and Schoonhoven, 1996; Mowery et al., 1998). In rapidly developing industries, where competition might be seen as a learning race, it is almost inevitable to engage in interfirm collaboration to identify new opportunities and learn about new technology (Powell, 1998). Accordingly, Teece (1992) argues that complex forms of cooperation are necessary for competition on a level of high technological sophistication especially in fragmented industries.

The combination of these core components leads to the dynamics of knowledge accumulation, which is based on the knowledge and competencies of the single actors but also characterised by collective progress (Lawson, 1999; Lawson and Lorenz, 1999). Regarding innovation activities, the following can be deduced: even though innovations, i.e. new products, processes,

or organisational forms, are ascribed to a single innovator or a small group of innovators, the whole environment and the system of relationships actors are embedded in are also crucial for the success of an innovative project. This idea is also referred to as *collective invention* (Allen, 1983) and processes of collective innovation. Thus, processes of collective innovation are based on the conscious and unconscious exchange of know-how.

## 2.2 Coordination of knowledge exchange through networks

The conscious exchange of technological knowledge between actors can be organised in different types of arrangements. The normative basis for a market organisation is a contract between the parties which relies on well defined property rights and actors largely communicate via the price mechanism. Certainly, there are markets for technologies where licences for patents etc. can be traded.<sup>3</sup> In functioning markets, the licensee pays the price for using the technology developed by the licensor who is protected by intellectual property rights.<sup>4</sup>

The transfer of knowledge can also be organised hierarchically; i.e. within firms where the researcher is obliged to leave the inventions to the employer. Here, the contractual obligations form the basis for a hierarchical structure of coordination.

We consider a third mode of organising the knowledge transfer which has little or no underlying contractual relationships and therefore lies in-between the two extremes of market (price mechanism) and hierarchy (contractual arrangements). This mode of transfer is based on bilateral information trading on an informal or less formal basis (von Hippel, 1987; Schrader, 1991). The notion of *informal know-how transfer* comprises the transfer of knowledge between scientists, researchers or engineers on trade fairs, conferences or during informal meetings. These arrangements are based on complimentary strengths, trust, and reciprocity and need time to develop (Powell, 1990; Teece, 1996).<sup>5</sup> Formalised research cooperations or collaborations can also

<sup>3</sup>See Arora et al. (2001a) and Arora et al. (2001b) for strategic aspects and the overview article of Geroski (1995) for different aspects of failures in markets for technology.

<sup>4</sup>Cohen and Klepper (1996), in a study not directly related to this topic, consider only 1 out of 31 high-tech industries as an industry where licensing of new technology is a relevant means of appropriating returns from R&D.

<sup>5</sup>Fehr and Gächter (2000) give an overview of experimental studies that reject the pure self-interest model of neoclassical economics in different situations and circumstances.

be counted thereto if contracts are incomplete due to the uncertainties of the innovation process. Cooperations might then provide the benefits of integration while avoiding some of the costs (Teece, 1996). Powell et al. (1996) argue that especially in industries where the knowledge-base is complex and expanding learning takes place in networks of interacting firms instead of individual firms.

The coordination pattern which underlies these bilateral informal or weak formal cooperative relations is called a network organisation. The functionality of networks is based on the principles of complementarity and reciprocity. This means that firms will only participate in these networks, if they expect to learn from other network members (complementarity) and if the transfer of knowledge is bi- or multilateral (reciprocity) (DeBresson and Amesse, 1991). In contrast to enforceable market contracts, networks are often more stable, in the presence of interdependent preferences, than market relations but more flexible than labour contracts.

### 2.3 Innovator networks

Networks of innovating firms are identified in different configurations: supplier-user networks, networks of pioneers and adopters, regional inter-industrial networks, international strategic technological alliances, and professional inter-organisational networks (DeBresson and Amesse, 1991). Despite these organisational arrangements, the physical interaction takes place between people. Interpersonal networks are considered an important channel for the diffusion of knowledge and information (Zander and Kogut, 1995; Zucker et al., 1998; Sorenson, 2003). Sorenson (2004) shows that the importance of these transmission channels depends on the complexity of the underlying knowledge-base, and in particular, that knowledge complexity limits the rate at which knowledge diffuses across geographic boundaries.

Following the sociological literature (e.g. Granovetter, 1973, 1983), only recently an economic literature assessing the properties of knowledge networks and its influence on the rate of knowledge diffusion has emerged (see for example Bala and Goyal, 1998; Cowan and Jonard, 2003a,b; Morone and Taylor, 2004). In performing simulations, these studies show that the rate of knowledge diffusion is highest in networks that exhibit small world properties, i.e. networks with short average path length and high degree of clustering (Watts and Strogatz, 1998).

In a reaction to these advances in theory, a growing number of studies use patent information to apply social network analysis in the field of economics and economic geography. In studies on inventor networks, inventors are linked directly by assuming relations between inventors who jointly worked on patents (Balconi et al., 2004; Fleming et al., 2004a, 2006). Fleming et al. (2006) for example investigate the influence of small-world properties on the innovative performance of regional networks. While agglomeration and short path lengths are positively related with innovative productivity, the small world variable shows insignificant. Another approach is taken in studies on innovator networks. Here, the applicants (innovators) are linked via common inventors ((Breschi and Lissoni, 2003; Singh, 2003, 2005; Cantner and Graf, 2006). In following that approach, Breschi and Lissoni (2003) could show that geographical proximity is not a sufficient condition for knowledge spillovers. Knowledge can rather ‘flow’ between actors that are close in social distance.

In following the latter approach, we study the network of innovators in Jena – a city which stands out of the mass of communities in the eastern part of Germany as a technologically and economically successful region (OECD, 2001; Cantner et al., 2003b; Fritsch et al., 2007). We map the regional networks of innovators by analysing patent applications at the German Patent Office which were disclosed between 1995 and 2001. The regional assignment of patents is based on the inventors’ residence, i.e., we use all patent applications with at least one inventor residing in the respective region to construct the networks. We thereby restrict our analysis to geographical proximity between the actors as being most relevant to foster interaction and thereby learning and specifically focus on aspects of technological and social proximity. This network of innovators constitutes the core of the local innovation system, which would also include political actors, norms, and institutions.

### 3 Research methodology and data

#### 3.1 Social network analysis

Social network analysis is a interdisciplinary methodology developed mainly by sociologists and researchers in social psychology, further developed in collaboration with mathematics, statistics, and computing that led to a rapid

development of formal analysing techniques which made it an attractive tool for other disciplines like economics, marketing or industrial engineering.

[...] [S]ocial network analysis is based on an assumption of the importance of relationships among interacting units.[...] relations defined by linkages among units are a fundamental component of network theories.

(Wassermann and Faust, 1994, p. 4)

There is a wide range of topics in economics, that employ methods of social network analysis. Some recent examples include the work of Cowan and Jonard, who evaluate the impact of the network structure on its performance by means of simulation (Cowan and Jonard, 2003a,b). Owen-Smith et al. (2002) compare the organisation and structure of scientific research in the United States and Europe by building networks of R&D cooperation. Breschi and Lissoni (2003) as well as Singh (2003) expand the study of Jaffe et al. (1993) and find that social proximity is more relevant for the degree of knowledge spillovers than geographical proximity. Balconi et al. (2004) analyse Italian networks of inventors resulting from common team-membership in patenting. They focus on the specific role of academic inventors in different technological classes.

The data requirements constitute a problem for empirical application of this approach in the field of economics. The usual procedure of taking samples of firms is not appropriate in analysing networks. Even if relational data were available one might miss firms that link unconnected parts of the network or the most central players of the network. The observed network structure would then not at all correspond to the actual relations. Samples can only be taken on the level of relations, i.e. not all possible relations between firms have to be analysed, but only the ones that are in the focus of the study. As a consequence, many empirical applications which study networks of innovators or inventors make use of patent data either by building citation or co-authorship networks. Patent data are widely available and databases are complete in the sense above (Balconi et al., 2004; Fleming et al., 2004b), as an indicator for innovative activity, patents are widely used and widely criticised (Lanjouw and Schankerman, 2004). The use of patents is problematic since not all novelties are or can be patented and in-

formation about the quality of patents is difficult to retrieve.<sup>6</sup> Since we are interested in the connections between actors in the process of innovation, the output in terms of patent quality is not of critical importance.

The insights that are and might be obtained by means of this methodology in accounting for specific linkages and the resulting structure outweigh its drawbacks if one is aware of the difficulties with the underlying database. We can obtain interesting and relevant information by asking not just ‘how many cooperative research projects do you perform?’ but rather ‘with whom do you cooperate on research projects?’

### 3.2 Data

Patents provide information about the applicant(s), let us call them innovator, which is usually a firm or public research laboratory, but might also be an individual.<sup>7</sup> You also find the actual inventor(s), i.e. the people who generated the knowledge that has been patented, as well as the technological classification of the patent. Following [Balconi et al. \(2004\)](#), we assume that inventors listed on the same patent know each other, and should have exchanged scientific or technical information.

We use data on patents that were applied for at the German patent office and were disclosed between 1995 and 2001. To include all patents that are relevant for Jena as an innovation system we filtered out all patents where at least one of the inventors named on the patent resided in Jena at the time of application. Altogether we could identify 334 distinct innovators on 1114 patent applications, employing 1827 inventors (977 of whom resided in Jena at the time of application) and covering 29 out of 30 technological classes. For the technological aggregation, patents have been classified according to a technology-oriented classification that distinguishes 30 technologies based on the International Patent Classification (IPC). This classification has been elaborated jointly by the Fraunhofer-Institut für Systemtechnik und Innovationsforschung (FhG-ISI), the Observatoire de Sciences et des Techniques (OST), and the Science and Technology Research Policy Unit of the University of Sussex (SPRU) to translate the rather technical patent classification

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<sup>6</sup>For a more detailed discussion on the usage of patent statistics in economics see [Griliches \(1990\)](#) or [Pavitt \(1988\)](#).

<sup>7</sup>We use the term ‘innovator’ to avoid confusion with the term ‘inventor’ which is used for the scientists and engineers who invent the novelty as in [Balconi et al. \(2004\)](#). Of course, we do not know, whether the patent applications lead to a marketable product.

into groups that are closer related to economic activities. To investigate the dynamics of the networks, we split the sample into two periods of equal length. The first period includes all patents disclosed between 1995 and 1997 while the second period covers the years 1999 through 2001. By dropping the year 1998 from the sample we lose 38 innovators. The rest can be divided into 157 innovating entrants, 107 innovators that exit, and 32 permanent innovators, which make up the core of the system.

## 4 Innovator networks in Jena

According to the outline of our paper given in the introduction, we now proceed to map the actors that make up the innovation system of Jena. We pursue two different approaches in building innovator networks with our data. The first approach to build such a network is to link the innovators by the kind of technological knowledge they have created. The more fields of research the innovators have in common, the closer they are related (technological overlap). The second possibility is related to the notion of knowledge transfer through personal relationships (e.g. [Saxenian, 1994](#); [Almeida and Kogut, 1999](#)). The main idea is that organisations, i.e. firms or research institutes, are related if scientists know each other through working on joint projects (cooperation) or move from one organisation to the other (scientist mobility).

Based on our data we analyse three different types of networks, all of which are built for the two consecutive periods (1995-1997 and 1999-2001):

**Technological overlap:** Linkages between innovators are formed whenever they patent in the same technological class. This network can be interpreted as the potential for cooperation.

**Personal relations** distinguished into:

**Cooperation:** When there is more than one innovator on a patent, there are as many linkages between all co-applying innovators as there are inventors.

**Scientist mobility:** Whenever a specific inventor is mentioned on patents applied for by distinct, not cooperating innovators a link between those innovators exists, since the inventor has worked for both.

The following example should provide the reader with a short introduction to the methodology and our data setup. For more details, we refer to the widely cited book by [Wassermann and Faust \(1994\)](#). Since we use patent data it is natural to provide an example in that context. The raw data for our example is given in table 1 and includes six patents ( $P_1$  to  $P_6$ ) by four innovators (applicants) ( $A_1$  to  $A_4$ ) with five inventors ( $I_1$  to  $I_5$ ) in two technologies (1 and 2).

**Table 1:** Example raw data

Patent	Innovator	Inventor	Class
$P_1$	$A_1, A_3$	$I_1, I_4$	1
$P_2$	$A_2$	$I_2$	2
$P_3$	$A_3$	$I_3, I_4$	2
$P_4$	$A_4$	$I_1, I_4$	1
$P_5$	$A_4$	$I_2, I_3$	2
$P_6$	$A_4$	$I_5$	2

If one wishes to construct a network of innovators where a linkage between the innovators  $A_1$  and  $A_2$  result from people having worked for both of them, one has to generate the 2-mode sociomatrix  $\mathbf{X}_p$ , where the rows are the innovators and the columns represent the inventors. Inventors are then the common ‘events’ of the innovators. The respective sociomatrix with respect to technological overlap would be represented by  $\mathbf{X}_t$ , with rows representing the innovators and columns representing the classes.

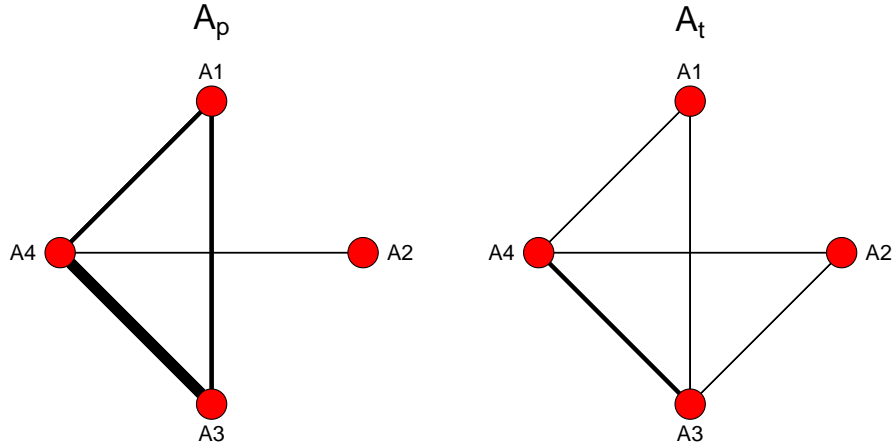
$$\mathbf{X}_p = \begin{pmatrix} 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 1 \end{pmatrix} \quad \mathbf{X}_t = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \\ 1 & 1 \end{pmatrix}$$

The square matrix that indicates the number of linkages  $a_{ij}$  between  $A_i$  and  $A_j$ , is called the adjacency matrix  $\mathbf{A}$ , which is computed as the product of  $\mathbf{X}$  and its transposed. Accordingly,  $\mathbf{A}_p$  is the adjacency matrix of personal

relations and  $\mathbf{A}_t$  with respect to technological overlap.

$$\mathbf{A}_p = \mathbf{X}_p \mathbf{X}_p' = \begin{pmatrix} - & 0 & 2 & 2 \\ 0 & - & 0 & 1 \\ 2 & 0 & - & 3 \\ 2 & 1 & 3 & - \end{pmatrix} \quad \mathbf{A}_t = \mathbf{X}_t \mathbf{X}_t' = \begin{pmatrix} - & 0 & 1 & 1 \\ 0 & - & 1 & 1 \\ 1 & 1 & - & 2 \\ 1 & 1 & 2 & - \end{pmatrix}$$

Since  $I_2$  has worked both for  $A_2(x_{22}^p = 1)$  and  $A_4(x_{24}^p = 1)$ , there is a linkage between  $A_2$  and  $A_4$ , indicated by  $a_{24}^p = 1$  in the personal relationships network  $\mathbf{A}_p$ . In the network of technological overlap, we find  $A_4$  to have patented in both technologies ( $x_{41}^t = x_{42}^t = 1$ ) and is therefore linked all other members of the network ( $a_{41}^t, a_{42}^t, a_{43}^t \geq 1$ ). The graphical representations of  $\mathbf{A}_p$  and  $\mathbf{A}_t$  are then given in figure 1.



**Figure 1:** Example networks

#### 4.1 The network based on technological overlap

Innovators can be specialised in a certain field of knowledge or instead be diversified. Building a network where innovators are connected by the overlap in technological interest we would expect diversified actors forming the center of the network, whereas the specialised innovators are positioned in the periphery. This exercise serves three purposes. First, it gives us a picture of the structure of the innovation system in different time periods. Are the innovators all focussing on the same technologies or do we see sev-

eral specialised groups of firms that form clusters in the periphery of the network? Second, we can identify the innovators in the center and the periphery, thereby investigating the roles of particular actors. Third, this type of network can be viewed as the potential for innovators to cooperate since the connected firms share a common knowledge base (Cantner and Graf, 2006).

We define technological overlap as the number of technological classes in which two actors both hold patents. This very simple measure of technological closeness might be interpreted as a necessary condition for cooperation as actors share a minimum of common knowledge which is needed for understanding each other. We know that this is not an ideal measure but we consider it as a minimum requirement for communication. Since our data does not include patent citations, we cannot follow the more elaborate methodology of Mowery et al. (1998). While other measures for technological proximity seem appealing at first, they have proven inconvenient for our purposes.<sup>8</sup>

Figure 2 visualises the Jena network of innovators, where nodes are innovators and edges result from an overlap in at least two technologies.<sup>9</sup> It comes as no surprise that the larger innovators form the center of these networks. Jenapharm is the only exception, being a large specialised firm in pharmaceuticals and therefore in the periphery. Carl Zeiss Jena and Jenoptik are the successors of the former VEB Carl Zeiss which dominated the economic structure of Jena during the socialist era in the GDR. This VEB was a highly differentiated ‘Kombinat’, i.e. integrated firm and already by visual inspection we see that they move towards the periphery of the network as they follow a strategy of higher specialisation. The University (FSU) on the other hand moves towards the center of the network and covers the broadest range of research fields in the second period.

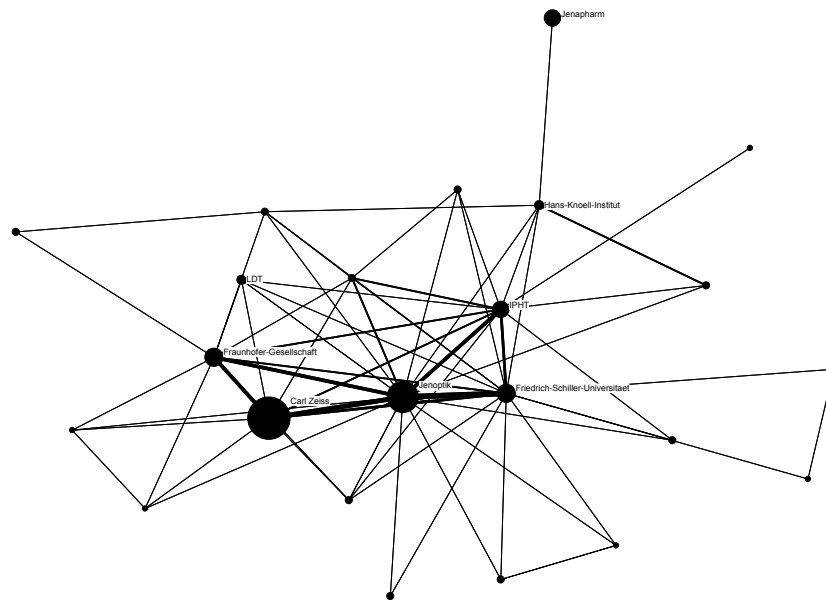
We do not observe any clear cut cluster formation within Jena for either

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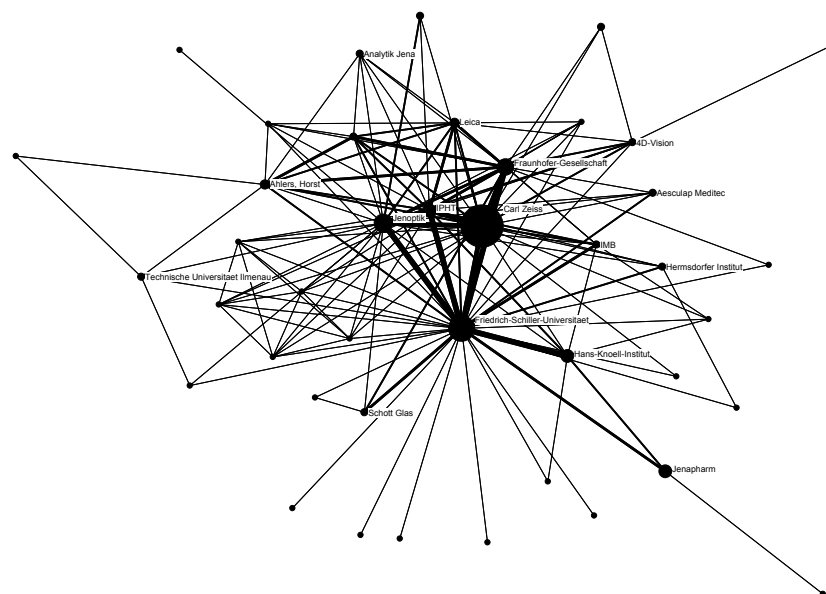
<sup>8</sup>Specifically, these measures lead to closeness between firms that have no technological overlap but patent in only one field while firms that patent in common technologies but also cover some different fields are more distant.

<sup>9</sup>This restriction is only used for visualisation of the network. The size of a node is determined by the number of patents, the width of an edge is proportional to the number of overlapping technologies. Isolated innovators are not displayed for reasons of lucidity. The network visualisation for this and the following figures was performed using NetDraw as implemented in UCINET 6 software (Borgatti et al., 2002) and multidimensional scaling with node repulsion and equal edge length bias as layout.

Technological overlap 1995-1997



Technological overlap 1999-2001



**Figure 2:** Potential for cooperation in Jena

period, it rather seems that the core has become denser while small innovators position themselves in the same types of technologies as the core. Even though we apply equal time spans for the division of the data, the size of the visualised network almost doubles from 23 innovators<sup>10</sup>, that have at least two technologies in common, to 42 innovators in the second period.

**Table 2:** Descriptive statistics of the networks of technological overlap

	tech <sup>95-97</sup>	tech <sup>99-01</sup>
No. of actors	139	189
No. of components	4	4
Size of largest component	135	179
No. of isolates	2	1
Density	0.149	0.165
Mean degree <sup>a</sup>	19.165	28.730
Network centralisation <sup>a</sup>	0.602	0.717
Overall graph clustering coefficient	1.228	1.200
Ave. distance (among reachable pairs)	2.003	1.879

<sup>a</sup> Networks have been dichotomised.

Table 2 summaries the descriptives of these two networks. Since there are only 30 technological classes, both networks are highly connected. We observe four *components*, i.e. disconnected parts of the network, in each period and one and two isolated actors respectively. Roughly 95 % of the actors are part of the largest component.

If  $g$  is the size of the network as measured by the number of actors and  $d_i$  is the degree, i.e. the number of connections, of actor  $i$ ,  $i = 1, \dots, g$ , then the *density*  $D$  of the network is defined as the number of all linkages divided by the number of possible linkages within the network  $D = \sum_{i=1}^g d_i / (g^2 - g)$ . The observation from visual inspection that the network has become increasingly connected is confirmed by the measures of density (0.15 to 0.17) and also by an increase of the mean degree from 19.2 to 28.7.

The degree centrality of actor  $i$  is the number of its ties divided by the number of possible ties  $C_i = d_i / (g - 1)$ . The *network centralisation* is then given by  $C = \sum_{i=1}^g (\max(C_i) - C_i) / (g - 2)$ . We find an increase in centralisation of the network from 0.6 to 0.7, which means that peripheral actors in the network are stronger connected to actors in the center and/or less connected to other peripheral actors.

Another structural measure for a network is the *overall clustering coef-*

<sup>10</sup>Innovators that have patented in at least two technologies, that are also covered by other network members.

*ficient*. It is calculated by averaging the clustering coefficients of all actors within the network. The node level clustering coefficients are calculated as the density of the neighbourhood, i.e. the network of actors directly linked to the respective actor. This measure slightly decreases from 1.23 in the first period to 1.20 in the second period. At the same time, the average distance between actors decreases from 2.00 to 1.88.

Summarising, we find increasing cohesion, which is interpreted as a stronger focus on core competencies, where the activities of the central actors become increasingly important for the whole network.

## 4.2 The network based on personal relations

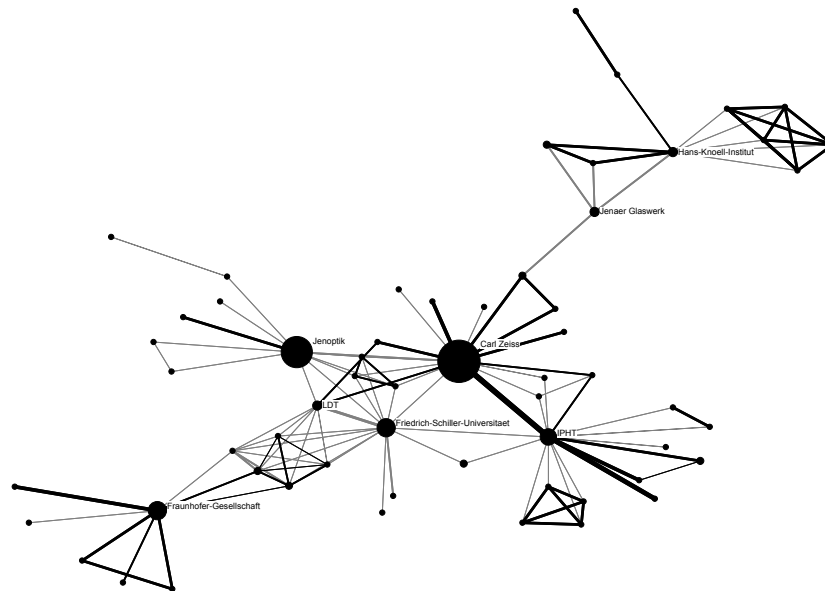
In the previous section we focussed on the technological competencies of the innovators in Jena. Performing within the same technological field, however, does not imply to be actually related to one another though. What really matters when we talk about regional and local innovation systems or innovator networks, are the interpersonal relationships in such systems.

[Arrow \(1962\)](#) already recognised worker mobility as a distinct source of knowledge spillovers. [Saxenian \(1994\)](#) and [Almeida and Kogut \(1999\)](#) show that the mobility of individuals is one possible mechanism of knowledge diffusion to existing firms, whereas [Klepper \(2001\)](#) as well as [Gompers et al. \(2003\)](#) focus on start-ups as a means of commercialising knowledge. [Cooper \(2001\)](#) shows theoretically that a higher rate of job mobility corresponds to greater overall technological progress because parts of the knowledge generated by the worker can be utilised by both firms involved.

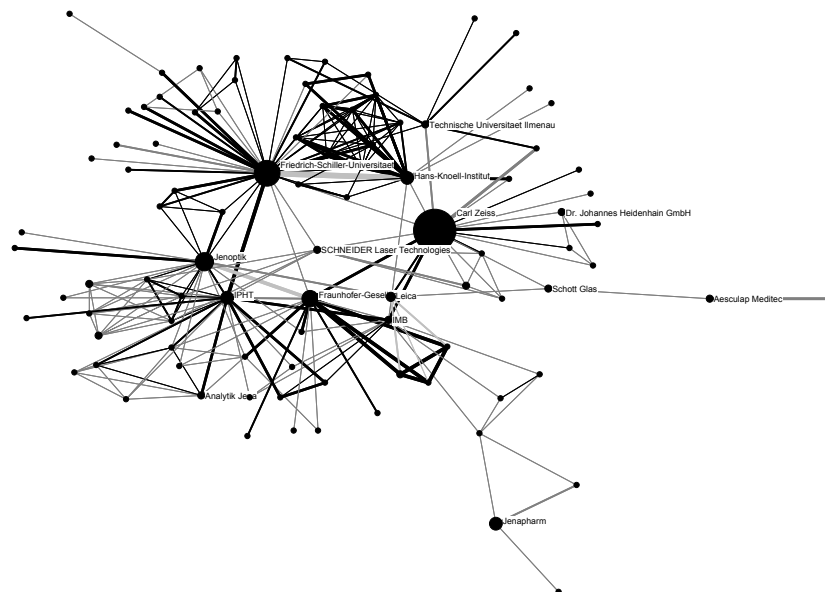
Due to the data that we use, we have the possibility to analyse a network of innovators that can be viewed as the lower barrier of actual relationships. On each patent we find information about all the scientists and engineers that were involved in the creation of the knowledge that led to this innovation (inventors). By creating a 2-mode sociomatrix where the innovators are the nodes (rows) of the network and the inventors on the patent are the characteristics (columns) of these innovators we can identify those inventors that have worked on research projects for more than on innovator, thereby creating linkages between these innovators. We assume that the more scientists have worked for two distinct innovators, the closer the latter are related.

We can distinguish two different possibilities how this relationship is es-

Cooperation and scientist mobility 1995-1997



Cooperation and scientist mobility 1999-2001



**Figure 3:** The network through interpersonal relations in Jena; cooperation is black, scientist mobility is gray.

tablished. The first way is by direct cooperation. Whenever we find a patent with more than one innovator (co-application), we assume it to be a cooperation. Of course, all the inventors on such a patent are then a ‘common event’ of all the innovators. We call the resulting network *cooperation*. The other possibility is less direct. If an inventor is mentioned on patents applied for by different, not co-applying innovators within one of the two periods of observation (1995-1997 and 1999-2001) we end up with a link between those innovators that is referred to as *scientist mobility*.

Besides the obvious increase in size of the visualised networks (figure 3) both types of networks are characterised by a different evolution of the network structure.<sup>11</sup> In table 3 we report the statistics for the networks of cooperation ( $co^t$ ), scientist mobility ( $sm^t$ ), and the network of personal relationships ( $pr^t$ ) which is an aggregate of both networks where the two former types of relations are not distinguished.

The analysis of components shows a trend towards less fragmentation. The share of innovators that are part of the largest component of the cooperation network increases from 8.6% to 31.2% and the share of innovators connected by scientist mobility in the largest component increases from 25.2% to 32.3%. If we abstract from the type of interaction connecting the innovators, almost 50 % of all innovators are part of the largest component of the network. The density of the cooperation network decreases (0.029 to 0.027) while it remains constant for the scientist mobility network (0.010). The overall effect is dominated by the effects of cooperation, which leads to a network of personal relationships which is less dense in the second period (0.040 to 0.037). Even though density is a relative measure for the structure of the network it is not invariant to the size of the network. Therefore, we calculate the mean degree to account for the connectedness of actors. While in the first period each actor had an average of 2.2 connections to other actors in the second period we observe an average of 2.8 connections via personal relationships.

The overall network becomes more centralised (from 0.109 to 0.184),

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<sup>11</sup>In the network visualisation, nodes are innovators irrespective of organisational form, edges between A and B result from an inventor named on patents held by both A and B. Only the largest component is displayed. Linkages through cooperation are black, linkages through scientist mobility are grey. If both types of linkages apply, we use a light grey. For large firms such as Siemens, which are not located in Jena, we only include patents with at least one inventor living in Jena.

**Table 3:** Descriptive statistics of the interpersonal networks

	pr <sup>95-97</sup>	pr <sup>99-01</sup>	co <sup>95-97</sup>	co <sup>99-01</sup>	sm <sup>95-97</sup>	sm <sup>99-01</sup>
No. of actors	139	189	139	189	139	189
No. of components	58	72	90	120	84	113
Size of largest component	59	94	12	59	35	61
No. of isolates	42	58	71	109	76	104
Density	0.040	0.037	0.029	0.027	0.010	0.010
Standard deviations	0.381	0.392	0.361	0.357	0.124	0.138
Mean degree <sup>a</sup>	2.201	2.815	1.065	1.534	1.137	1.344
Network centralisation <sup>a</sup>	0.109	0.184	0.051	0.137	0.102	0.057
Overall graph clustering coefficient	2.452	2.191	3.634	2.833	0.856	0.648
Ave. distance <sup>b</sup>	3.581	2.799	1.699	2.974	2.634	3.325

<sup>a</sup> Networks have been dichotomised; <sup>b</sup> among reachable pairs

which is also due to the development in formal cooperation (from 0.051 to 0.137) whereas centralisation decreases in the scientist mobility network (from 0.102 to 0.057). All networks show a tendency towards less clustering.

To summarise these observations, it seems as if the large, core actors within the network increasingly focus on formal cooperation while the smaller, surrounding or peripheral actors rather have contacts through informal, personal relations.

## 5 Entry and exit

### 5.1 Technological overlap

As was already noted before, we can characterise the innovators according to their innovator status, i.e. entry, exit, and permanent. If network positions really matter for the performance of single actors one would suspect that innovators who exit the system have to do this because of a weak position – in the sense of being less connected or in the periphery – therein (Powell et al., 1999). For the entering firms, we should observe a higher number of connections to the core of the existing network. The analysis is performed for the network of technological overlap and for the networks of personal relations below.

To illustrate our expectations regarding the technological position, we distinguish two cases of entry: local firm foundings and firms that relocate. For local firm founders who are educated or work within a particular system

we expect a higher probability of being engaged in the same activities as before. A spin-off firm for example is usually active in related technology fields as the parent organisation. Firms that are relocating to the region should also be active in technologies that overlap with competencies of existing firms. If we expect them to be quite aware of the characteristics of this region, the technological competencies of the site should be – at least for innovative firms – a relevant criterion. Such a self-organising process on the system level would lead to a development where actors active in technologies that exhibit a number of actors below some threshold level either leave the system and search for a better location or just stop innovating at all. New entrants on the other hand are attracted by the strengths or core capabilities of the network for example due to a thick market for skilled labour or potential partners for trade or cooperation in interrelated industries (see [Swann and Prevezer, 1996](#), for an analogous argument).

We analyse these differences between both periods in the network of technological overlap. Calculating mean degrees for the different groups mentioned above – entry, exit, and permanent – we distinguish between relations within the group and between the groups. The resulting values and tests for the significance of differences between the mean degrees are given in table 4. Since we cannot assume a normal behaviour of the degrees of the network members, we perform the nonparametric Mann-Whitney or Wilcoxon rank sum test to examine our above reasoning. The tests are performed by column, i.e., we compare exiting innovators of the first period with the entering innovators of the second period and so on.

Regarding the different roles of exiting innovators and entrants, we observe a stronger connectivity within the entering group itself (18.191 compared to 8.729 for the exiting group), but also with respect to the linkages with the permanent group (7.592 compared to 6.738 for exit). While the former observation, that the entrants are a more homogeneous group, is significant, the latter is not on an acceptable level of significance (p-value of 0.208). The values in the third and fourth column are based on the same number of connections but in calculating the mean they are divided by a different number of focal actors. Accordingly, we notice more technological connections between the permanent innovators and the entering innovators (37.250) as compared to the exiting group (22.531). The permanent innovators themselves increase their technological overlap significantly between the

**Table 4:** Technological overlap: Mean degree (within and between blocks)

	<b>within</b>	<b>between</b>	<b>between</b>	<b>within</b>
1995-1997	exit	exit and permanent	permanent and exit	permanent
N	107	107	32	32
mean degree	8.729	6.738	22.531	15.125
sd	(5.984)	(4.187)	(22.361)	(14.914)
1999-2001	entry	entry and permanent	permanent and entry	permanent
N	157	157	32	32
mean degree	18.191	7.592	37.250	19.563
sd	(16.196)	(4.825)	(38.756)	(17.629)
Significance of difference between mean degrees				
	Mann-Whitney		Wilcoxon rank sum test	
W	5854	7906.5	101.5	130
p-value	0.000	0.208	0.002	0.011

Note: One-sided tests are performed with  $H_0$  as no difference between samples and  $H_1$  in the direction of the observed differences.

two periods from 15.125 to 19.563. These results are in line with the above arguments and fit to our expectations. With respect to our previous result of an increasing cohesion of the network of technological overlap, the findings here indicate that both, the permanent innovators as well as the entrants (compared to the exiting innovators), tend to increasingly concentrate on the technological core competencies of the network as a whole.

## 5.2 Personal relations

In a next step, we are interested in the relative positions of different groups in the networks of cooperation and scientist mobility. As in the analysis of technological overlap, we expect entrants to be closer to the core than exiters. For the theoretical argument, we distinguish between local entrants and entrants that relocate. We know from a related study that a large fraction of high-tech firms in Jena are spin-offs or academic start-ups ([Cantner et al., 2003a](#); [Fornahl and Graf, 2003](#); [Graf, 2006](#)). These types of establishments are characterised by previous employment of their founders in incumbent firms or research institutes. If a scientist has worked and patented for members of the network and then starts his own firm with a patented innovation

it will show up as scientist mobility in our data.<sup>12</sup> Such an actor gained insight into the network of innovators during previous employment and might therefore make use of this type of know-who to form cooperations. Firms that move to Jena might have learned about the location via previous contacts to network members, for example through cooperation. Being involved in these networks of personal relationships provides access to knowledge external to the firm. As to the exiters, those firms may lack these contacts and are therefore cut off important knowledge channels. In consequence, this should lead to decreasing innovation and exit from the network. An opposing argument could be that since exiting innovators are presumably older than the entering innovators they had more time to establish linkages through cooperation and scientist mobility.

Tables 5 and 6 report the results for the mean degree in the networks of cooperation and scientist mobility, calculated within and between the groups of exiters, permanent innovators, and entrants in the two periods. Our first observation regards the comparison of the connectedness between exiting and entering innovators within their respective group (column 1 in each table). The exiting innovators have significantly ( $p = 0.066$ ) more linkages through cooperation than the entering group (3.084 versus 2.242) and slightly, but not significantly more linkages through scientist mobility (0.561 versus 0.497). While this can be explained by the age of the exiting innovators, the more interesting result regards the connections of these two groups with the permanent innovators. The entering innovators cooperate significantly ( $p = 0.003$ ) more with the permanent ones than the exiting innovators did (1.516 versus 0.710) and have also more linkages through scientist mobility (0.637 versus 0.514) even though not to a significant degree. A glance at figure 3 shows that these linkages with permanent innovators are especially with few large actors in the center of the network, which explains the large standard deviation of the mean degree between permanent and entering innovators (third column in table 5). The permanent innovators themselves (fourth column in tables 5 and 6) show a significant increase in linkages through cooperation (from 2.563 to 3.938) and especially in scientist mobility (from 0.938 to 2.500).

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<sup>12</sup>In cases where whole departments or research teams spin-off, we would observe very large scientist mobility between the spin-off and the original employer. However, such extreme cases are not present in our data.

**Table 5:** Cooperation: Mean degree (within and between blocks)

	<b>within</b>	<b>between</b>	<b>between</b>	<b>within</b>
1995-1997	exit	exit and permanent	permanent and exit	permanent
N	107	107	32	32
mean degree	3.084	0.710	2.375	2.563
sd	(5.207)	(1.873)	(5.375)	(5.346)
1999-2001	entry	entry and permanent	permanent and entry	permanent
N	157	157	32	32
mean degree	2.242	1.516	7.438	3.938
sd	(4.424)	(2.623)	(17.005)	(6.710)
Significance of difference between mean degrees				
	Mann-Whitney		Wilcoxon rank sum test	
W	9191.5	7111	34.5	49
p-value	0.066	0.003	0.136	0.100

Note: One-sided tests are performed with  $H_0$  as no difference between samples and  $H_1$  in the direction of the observed differences.

**Table 6:** Scientist mobility: Mean degree (within and between blocks)

	<b>within</b>	<b>between</b>	<b>between</b>	<b>within</b>
1995-1997	exit	exit and permanent	permanent and exit	permanent
N	107	107	32	32
mean degree	0.561	0.514	1.719	0.938
sd	(1.361)	(0.883)	(2.976)	(1.900)
1999-2001	entry	entry and permanent	permanent and entry	permanent
N	157	157	32	32
mean degree	0.497	0.637	3.125	2.500
sd	(0.965)	(1.415)	(4.030)	(2.700)
Significance of difference between mean degrees				
	Mann-Whitney		Wilcoxon rank sum test	
W	8166.5	8613	66.5	20
p-value	0.695	0.668	0.008	0.000

Note: One-sided tests are performed with  $H_0$  as no difference between samples and  $H_1$  in the direction of the observed differences.

Overall, innovative entrants in Jena seem to be better integrated into the network of personal relations than actors who, for whatever reasons, stopped innovating. This finding is consistent with our above reasoning and results of [Powell et al. \(1999\)](#) that the network position has an important influence on firm performance. The observations regarding the connectedness of entrants and exiters within their group are not contradictory to our argument. Actors

that enter such a network are certainly more aware of incumbents than of actors which enter during the same period. Knowledge about other potential partners for knowledge exchange needs time to develop.

Since we only analyse two periods, its difficult to view this finding as a general result. Surely, it needs to be qualified through further research. Let us nevertheless assume this conjecture holds: Would this not lead to ever increasing density of the network? We think not. Since the ties that constitute the networks cannot assumed to be persistent over very long periods of time, it might well be that formerly well connected actors become more isolated over time, therefore becoming a candidate for subsequent exit.

## 6 Concluding remarks

Social network analysis has been shown to be a valuable tool for a deeper understanding of innovation processes on a regional level. Our study of the innovator network in Jena led to interesting results with respect to the general structure of network, its main actors, and changes therein. For example, we observed growth (in the number of actors and in the number of patents), increasing interaction and a tendency towards increasing specialisation for the network as a whole. The analysis of the network of technological overlap leads us to conclude that the dynamics of the system is directed towards an increasing focus on core competencies of the local innovation system; i.e. innovators on the periphery of the network exit and new entrants position themselves closer to the core of the network. Thus, new innovators and exiting innovators in Jena have shown to be different regarding their network positions. From this we presume that a critical mass of innovators is necessary for a specific technology to ‘survive’ within a local system. A success-breeds-success mechanism on the level of the technology will then lead to an increasing specialisation of the system in these technologies. The same dynamics regarding the network positions of entering and exiting innovators are observed when analysing the cooperation and scientist mobility networks. Further research in this line is needed to test hypotheses regarding the relationship between network positions and the innovative performance of actors and to analyse the influence of network structure on the innovative success of regional networks.

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