Kroll, Henning

Working Paper

Spillovers and proximity in perspective: a network approach to improving the operationalisation of proximity

Arbeitspapiere Unternehmen und Region, No. R2/2009

Provided in cooperation with:
Fraunhofer-Institut für System- und Innovationsforschung (ISI)

Fraunhofer ISI

Working Papers Firms and Region
No. R2/2009

Henning Kroll

Spillovers and Proximity in Perspective

A Network Approach to Improving the Operationalisation of Proximity

Fraunhofer
ISI

Contact:
Fraunhofer Institute for Systems
and Innovation Research (Fraunhofer ISI)
Competence Center "Policy and Regions"
Breslauer Strasse 48
76139 Karlsruhe, Germany
Telephone: +49 / 721 / 6809-138
Telefax: +49 / 721 / 6809-176
e-mail: christine.schaedel@isi.fraunhofer.de
URL: www.isi.fraunhofer.de

Karlsruhe 2009
ISSN 1438-9843

Contents Page

Tables and Figures

1 Introduction

The impact of knowledge flows in regional innovation systems and regional clusters has been subject to a broad debate in the past two decades. From its very beginning, this discussion has developed alongside other debates on worldwide sectoral innovation systems and international networks of knowledge exchange in multinational firms. Not always, however, have those debates been well aligned in theory, and even less so in empirical work.

During the past five to ten years, increasing conceptual discussions have emerged regarding the linkages between intra-regional and inter-regional knowledge flows. A broad array of studies has discussed the issue which mix of inter-regional and intra-regional knowledge sourcing is conducive to create a vibrant regional system of innovation (e.g. Bathelt et al. 2004; Scott 1998) and corresponding political debates have emerged in many national states and at the European level (e.g. European Commission 2008). In short, there is consensus that, even though localised knowledge flows may not be the prime determining factor for regional innovation systems in a globalised world, regions play an important role since they provide a localised interface where global and local flows knowledge intersect, are adapted and recombined (in the sense of Cohen/Levinthal 1990) and thus learning effectively takes place. An important consequence of this train of thought is that the innovative output of a region cannot be predicted based on the amount of effort put into innovative activities at the regional level alone (nor, for that matter, the immediate vicinity). The degree to which actors in a region can draw on external knowledge sources is likely to significantly influence the effectiveness of the transformation of regional inputs into outputs (Gallié 2009). Regions, even more than nations, will in many cases be learning systems (in the sense of Viotti 2002) rather than innovation systems.

Much quantitative work, in contrast, remains centred on the regionalisation of the established knowledge production function (KPF) based approach which puts a focus on regional attributes rather than the degree of networkedness of the regions under study. Although many of those studies aim to take into account inter-regional knowledge flows as a complement those are mostly conceptualised in terms of knowledge spillovers and often operationalised as spatially lagged variables or through residual analysis (for a technical discussion cf. e.g. Anselin 1988). Based on such multivariate analysis, regional knowledge spillovers are often found to be significant, but to make but a small contribution to regional development (Bottazzi/Peri 2003) at least when controlling for a high number of regional attributes (Tappeiner et al. 2008).

This paper will not advocate discarding these established approaches, which have provided important contributions to our understanding of regional innovation processes and enlightened our understanding of regional spillovers. Nonetheless, based on what we know from conceptual papers and empirical studies they appear unduly narrow in that, with interregional networking, they omit one very important determinant dimension of innovative activities. This appears particularly relevant when one takes into account that the KPF approach was originally designed for the closed-system national level, rather than open-system regions. As a consequence, it is hard to draw robust conclusions on both the effect of regional inputs and the existence of spatial knowledge spillovers, when other forms of knowledge flows remain unaccounted for and an important control variable thus missing.

This paper will argue that, given the abovementioned caveats, the ambiguity of the findings on regional spillovers in the literature is not really that surprising. For the same reason, however, it will point out that this should not tempt us to dispute the existence or the relevance of regional spillovers altogether but motivate us to complement and improve future models. Against an existing theoretical background which stresses the crucial importance of inter-regional knowledge exchange, it appears a logical point of departure to develop approach that at least attempts to capture relevant inter-regional flows of knowledge.

2 Conceptual Background

Knowledge Generation and Transmission

The generation and transmission of knowledge is a complex concept the different dimensions of which have been extensively discussed in prior literature (e.g. Nonaka 1991; Nonaka et al. 2000; Polanyi 1967). Since it aims to discuss the foundations of processes of innovation this paper will focus on technological knowledge that can be applied in the production process in the nearer future. A suitable indicator to measure the generation of such knowledge are patent applications, since, to be accepted, the invention documented in an application must not only fulfil the criteria of novelty and a sufficient inventive step but also that of commercial applicability (Schmoch 1997). While not all patent applications are filed with the intention to actually make commercial use of them (broad hedging and blocking strategies are common among many firms, cf. Blind et al. 2006), by legal definition, they are evidence of a process of knowledge generation (Hinze/Schmoch 2004; Schmoch 1997). Nonetheless, the validity of the indicator remains somewhat impaired by the fact that this logic is unidirectional. While it is quite possible to convincingly argue that a reliable share of all patent applications does indeed reflect the generation of application oriented knowledge it could not be claimed that in turn all such knowledge is reflected in patents. Many firms prefer secrecy to patenting as a means of IPR protection and in some sectors this preference is more widespread than in others (Blind et al. 2006). By definition a patent is an act of codifying knowledge so that implicit knowledge is not accounted for. As a consequence, some applications may only reflect a decision to protect application oriented knowledge which was in principle available before (Blind et al. 2006). To a degree, patent applications are therefore by themselves a fuzzy indicator. On the other hand they are so far the best of all possible alternatives available for situations for which a survey based approach is not a viable alternative (Schmoch 1997).

Moreover, fuzziness in studies of knowledge generation and transmission has so far also resulted from a number of other sources. Since it is the key aim of this paper to address the proximity issue, it will in the following focus on the patenting indicator as one of many indicators that reflect knowledge generation for which this issue can be discussed. Its general deficiencies will thus likely affect all derived measures to a comparable extent so that for the purpose of this exploratory study they do not need to be taken into account.

Knowledge Spillovers: Spatiality vs. Proximity

While the notion of regional spillovers is well established and empirically validated it suffers from a certain fuzziness in definition. In many studies its definition is mostly technical and not very well operationalised with regard to the actual processes of knowledge exchange that it aims to address (Breschi/Lissoni 2001). Consequently, its application can turn into a walk on shifting sands for three reasons:

Firstly, available data on innovation are seldom available in a format suitable to capture the idea behind regional spillovers. A concept quite typically applied in urban science, marketing and criminology where it can draw on data available for individual housing blocks or at least quarters does not lend itself easily to analysis based on larger, irregularly shaped regions among which adjacency is a somewhat elusive concept. Moreover, knowledge spillovers *within* the respective regions remain entirely unaccounted for. Sometimes very large regions are chosen to define adjacency (Tappeiner et al. 2008). Given that empirical evidence on spillovers suggests that the reach of relevant knowledge flows hardly exceeds 250 km, is constrained by national borders and subject to strong distance decay (e.g. Moreno-Serrano et al. 2005) it appears questionable, whether e.g. a spatial lag analysis based on NUTS1 regions (with an *average* diameter of around 250 km) can really be meaningful. It is thus no surprise that ambiguous findings on regional spillovers have resulted from past studies.

Secondly, other than in the early studies of Jaffe et al. (1993) and also more recent studies on USPTO data such as Singh (2005) that based their analyses on patent citations and thus a defined measure of connectedness, approaches to determine if spillovers are present do not always go to sufficient length to establish a foundation for the claim that they really capture knowledge flows. Instead, a number of them tends to make use of spatially lagged variables or spatial error terms to empirically determine whether adjacent innovative activity matters, and if so, knowledge spillovers are suggested as the reason (e.g. Anselin et al. 1997; Bottazzi/Peri 2003; Moreno-Serrano et al. 2005). As Tappeiner et al. (2008: 862) rightly put it, this "is a mere technical approach and there is no indication on the transmission mechanisms that cause knowledge to diffuse and decay. In other words, there is no real evidence that knowledge really spills over". Thus, a judgement whether knowledge is actually exchanged cannot always be made. Quite possibly, the empirical findings on knowledge spillovers would be different if they could draw on variables that really capture knowledge exchange.

Thirdly, and most importantly, next to all findings on research and innovation systems, both national and regional, suggest that in a globalised economy spillovers can not meaningfully be defined based on geographical proximity alone (Bathelt et al. 2004; Breschi/Lissoni 2001; Scott 1998). The fact that both intra-regional and inter-regional knowledge flows matter is substantiated by so large a body of theoretical and qualitative empirical literature that only a brief selection can be reviewed here.

On the conceptual side, criticisms against an undue neglect of non-localised networks (Amin/Cohendet 1999; Cumbers et al. 2003; Humphrey/Schmitz 2002; Markusen 1999; Oinas 1999) have closely followed the renaissance of the emphasis on localised networks under the headings of rediscovered industrial district notions and the new surge of regional innovation system, cluster and learning region approaches. Early readings that modern regional innovation systems, like 19th century industrial districts, were to be understood as mostly self contained entities with no significant external linkages were therefore possibly never really in the sense of Cooke (2001) (Asheim/Coenen 2006). Certainly, they can neither be sustained theoretically nor have they so far been empirically corroborated for a European context characterised by concentration, spatial hierarchy, and multi-centricity (Boschma/Lambooy 2002; Crescenzi et al. 2007; Gallié 2009; Navarro et al. 2008; Taylor/Hoyler 2000; ter Wal/Boschma 2009; Vence-Deza/Gonzáles-López 2008; Verspagen 2007).

In line with Castells' (1996; 2002) concept of a network(ed) society and the world cities literature (e.g. Sassen 2002; Taylor 2004), regions are generally assumed to be dependent on knowledge influx from sources beyond their immediate vicinity (Asheim/Coenen 2006; Bathelt et al. 2004; Maillat 1998; Scott 1998). Many studies have elaborated on the multi-level nature of innovation systems (e.g. Asheim/Coenen 2006; Bunnell/Coe 2001; Castells 2002; Karlsson et al. 2008). Recent publications of the EC Commission suggest that this applies to regions both peripheral and central (Kroll/Stahlecker forthcoming). Apparently, a broad concept of proximity is needed to comprehend and empirically capture the nature of knowledge spillovers. This paper follows Asheim and Coenen (2006) in that "in a globalising economy characterised by vertical disintegration and distributed knowledge bases, the important perspective ought to be the *interdependences* between regions and nations where the deciding criteria must be the location of core activities [..] and their connection to regional knowledge infrastructures." It should be added that in an emerging Europe of Regions the interdependences needs not only to be investigated with regard to the mother nation in which the region is located, but also with regard to other regions and nations in at least a European context.

Proximity: A Multidimensional Concept

While it is generally agreed that proximity is a necessary condition for knowledge exchange, it cannot be reduced to a spatial concept (Boschma 2005; Maliepaard/Oosterom 2006). Hence, a network based approach will be needed to develop a notion of the non-spatial adjacency of regional innovation systems (Cooke 2001; Cooke et al. 2004). The key question thus becomes on what concept of proximity and ultimately what evidence this network approach can meaningfully be based.

Scientists from different disciplines have established that in practice different dimensions of proximity matter, overlap and interact (Lagendijk/Lorentzen 2007). Within the scope of this paper, for the sake of brevity, no comprehensive review can be attempted, which is available elsewhere (e.g. Boschma 2005).

The most commonly highlighted dimensions of proximity included in most typologies (cf. e.g. Boschma 2005), however, can be summarised as

- *social proximity* (cf. e.g. Granovetter 1973; Granovetter 1985; Polanyi 1944; Sörensen 2003), socially embedded relations between agents at the micro level.
- *organisational proximity* (cf. e.g. Cooke/Morgan 1998; Gilly/Torre 2000) referring to at least contractually fixed linkages within and between organisations (strong ties, established hierarchies).
- *institutional proximity* (cf. e.g. North 1990) sharing of value and norms between a group of actors at the macro-level to make life meaningful and predictable

In a globalised world, social relations, organisations as well as institutions do not have to be localised (alumni networks, multinational corporations, sectoral culture), although they can be (local political networks, local trade associations, local cultures). Case studies have repeatedly demonstrated that collaboration between the same kinds of organizations did not need to be localised when enough institutional proximity was given between the firms (e.g. Ponds et al. 2006). Similarly, effects of co-location have been found to diminish when controlling for interpersonal ties (Singh 2005).

This plethora of approaches and their comparatively high degree of abstraction provides a challenge to operationalisation. Quite clearly, data on these concepts cannot be obtained other than through surveys. Consequently, for the purpose of this study it was decided to step down one level of abstraction and to subsume the different forms of non-spatially defined proximity under a practically better observable notion of 'collaborative proximity' (Breschi/Lissoni 2001; Singh 2005) as collaboration can be assumed to have been induced by and thus to be based on a certain degree of social, organisational or institutional proximity or a combination of them.

Relevant data on inter-regional collaboration in the field of innovation can be obtained from patent statistics. In studies of the United States the issue is typically addressed by considering patent citations (e.g. Jaffe et al. 1993). In a European Context, however, this is would not be a meaningful procedure, as under EPO rules, most citations are added by the patent examiner rather than by the inventor himself, so that citations are not a valid measure of interaction.

This paper will therefore take recourse to co-patenting as an indicator of collaboration, even if certain caveats apply, such as the overall low number of cases are associated with it. Nonetheless, the joint mention of two inventors in a patent at least strongly suggests that two or more actors have been committed a joint effort to the development of a technology (cf. Singh 2005). A certain amount of knowledge exchange can plausibly be assumed to have taken place in that endeavour. Even though joint attributions may occur for reasons other than co-operation, there is no general underlying logic structurally different from collaboration (which indeed there is for citation). Co-patenting has therefore repeatedly been suggested as a method to analyse cooperative networking in the field of innovation (e.g. ter Wal/Boschma 2009).

With this tool in hand we can further develop the notion of knowledge spillovers by regarding geographic proximity as "neither a necessary nor a sufficient condition" (Boschma 2005) without discarding its contribution entirely. It will be argued that spatially lagged variables are of limited utility to operationalise knowledge spillovers as generally the "space of place [i.e. location, adjacency]" and the "space of [knowledge] flows" do not necessarily overlap (Boschma/ter Wal 2007). Nonetheless, they do remain an important descriptor of the relevance of adjacent activities when other forms of proximity are controlled for.

In summary, this paper will argue that many of the existing quantitative findings do not allow us to question whether or attempt to falsify the claim that "knowledge really spills over". It will be argued that, besides all inaccuracy due to fuzzy operationalisations of geographical proximity in its own right, the ambiguous empirical evidence on regional spillovers is to an even stronger degree a result of the fact that the concept of proximity which underlies all conceptualisations of knowledge spillovers needs to be further developed.

3 Assumptions/Hypotheses

Based on the theoretical argument laid out above, the following assumptions made regarding the impacts of co-operative proximity be tested based on the following hypotheses.

Assumption/Hypothesis 1:

a) The connectedness of a European NUTS 2 region in the European co-patenting network will substantially predict the degree of inventive activity as well as patent intensity in that region. As explanatory variables for inter-regional connectedness often correlate strongly (Bonacich et al. 1998), the direction and significance of univariate effects will not differ much irrespective of the measure used.

b) When collaborative activities really act as "pipelines" (Bathelt et al. 2004), a "network lagged variable" will yield a higher explanatory power than 'mere' network measures as it adds information on the overall innovative potential in other regions that a region is connected to.

c) When highly correlated measures of connectedness are pooled together as explanatory variables in a multivariate model, some specific effects will turn negative while others will vanish. Possibly, however, some robust effects can nevertheless be identified. If so, these are likely to differ between the models for total inventive activity and patent intensity.

Assumption/Hypothesis 2:

a) Measures of connectedness and a 'network lagged variable' will yield higher explanatory power than traditional spatially lagged variables as theory suggests that connectedness in a network defined by co-operative proximity is a more relevant predictor of innovative activity than the mere potential for spillovers based on geographic proximity.

b) Nonetheless, when added to a model including network measures, spatial lagged variables will retain explanatory power as theory suggests that they contain information on knowledge flows that is not yet or at least only insufficiently covered by the network measures.

Assumption/Hypothesis 3:

a) Effects will remain are stable under controls for key attributes of the local innovation system. Given the likely contingency of a region's innovative potential and its co-patenting activities with other regions, both approaches will each on its own yield high explanatory power.

b) Relevant network measures with high explanatory power are likely to significantly improve a model based on regional attributes while spatially lagged variables are not. The reason for this claim is that all highly innovative regions are likely to be interconnected in some way, while they will not in all countries necessarily be surrounded by other innovative regions.

4 Methodological Approach, Data Source and Delimitation of Sample

To conduct an analysis to shed light on the theoretical issues outlined above, four main types of variables are needed:

- dependent variables to measure knowledge production (precisely: inventive activity): total patent applications and patenting intensity (applications per inhabitant),
- measures of connectivity: network measures or 'network lagged variables',
- traditional spillover measures (spatially lagged variables),
- control variables (regional attributes commonly used in KPF approaches).

Dependent Variables

Data for total patent applications were directly generated from the most current and reliable source for patent data that is openly available: the PATSTAT database. Data from this database were regionalised to NUTS 2 level by means of the mid-2008 version of the REGPAT method of regionalisation developed by the OECD (2008) which allows us to localise all addresses in patents up to the year 2004. For the purpose of this study, a sample was taken covering the years from 2000 to 2004. Patent intensity data (applications per inhabitant) were calculated with reference to the 2000-2004 mean taken from Eurostat regional population statistics.

While it could be argued that an approach which at least refers to a KPF concept should not neglect the time dimension, the robustness of this analysis would likely be significantly impaired by the fact that particularly in small regions figures are very small and single figures are easily distorted by singular events. Intentionally, therefore, a five year average was preferred.

Measures of Connectivity

To find suitable indicators to measure connectivity in the network, a first exploratory regression was conducted to develop an understanding of the general relations between co-patenting activities in a region on the one hand and overall patent application activity as well as patent intensity on the other. The results are displayed in Table 1.

While the total number of co-patent applications in a region has a positive effect on both overall patent application activity and on patent intensity, the effect of the share of co-patenting in total regional patenting is strongly and significantly negative. Apparently, there are at least two different and independent effects to be observed, the first of which could be interpreted as a size effect (some regions are the source of both a high number of overall applications and a high number of co-patent applications) while the other could be interpreted as reflecting some sort of dependence phenomenon, relevant for regions with lower patent activities and intensities in which the share of co-patent applications is higher role despite their lower overall number.

The conclusion from this first check thus is that the issue of collaborative proximity (in the following also: geodesic proximity or network proximity) can not easily be expressed by referring to a "general degree of external connectedness" but should from the outset be addressed by means of a concept comparable to that of spatial adjacency: via network measures derived from a complete region-to-region network.

Table 1: First Check of the Effects of Co-Patent Aplications on Inventive Activity and Patent Intensity

	Total EPO Patent Applications			Patent Intensity		
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Total number of co-patent applications	1.309904***		1.270753***	.6623643***		.6293056***
Share of co-patents in total applications		-27.58736***	-17.25405***		-17.40299***	-12.2857***
R²-adj=, n=	0.8798, 235	0.0984, 235	0.9171, 235	0.6768, 235	0.1204, 235	0.7321, 235

Source: PATSTAT, REGPAT, own calculations

Consequently, a co-patenting network matrix for European NUTS2 regions was developed on the basis of the OECD's REGPAT inventor regionalisation for the PATSTAT database. Co-patenting relations reflect full counts, i.e. a patent with inventors from e.g.

the three regions R_1, R_2 and R_3 will be counted as a link between R_1 and R_2, R_2 and R_3 as well as between R_1 and R_3. The reason to do so is that it can be argued that the joint effort reflected in the patent has "established proximity" between all pairs of regions whereas there is no plausible reason to assume that the degree of proximity established between, say, R_1 and R_2 should be impaired by the fact that a third inventor from R_1 has also been part of the team.

To improve the differentiation between regional spillovers based on geographic proximity and spillovers based on collaborative proximity, co-patenting relations between different NUTS2 regions were only counted when at least two of the listed inventors lived in NUTS3 regions whose geographic centres are not within a range of less than 100km. Thus, it should have been possible to exclude most artefacts resulting from cross-border commuting, i.e. inventors living in different NUTS2 regions but actually commuting to and working together in the same organisation. Distances between NUTS3 regions were calculated using official EU map data for NUTS 2/3 region boundaries (Eurostat 2008) and the GeoDa spatial analysis software (Anselin et al. 2004). The resulting co-patenting network is plotted in Figure 1.

Evidently, the co-patenting matrix reflects the degree of decentralisation of economic activity in the different national states as well as the different sectoral specialisations in regions which in turn determine the regional propensity to apply for patents and co-patents. For example, the high degree of economic decentralisation and the high degree of economic and innovative activity in patent intensive industries in Germany results in a high degree of networking among many different German regions, whereas for example regions in France are scarcely connected to other regions than Paris (FR10) or Rhône-Alpes (FR71). Similarly, while in most countries there are a limited number of regions which connect internationally, in decentralised Germany quite a number of different regions have such connections. As a result, a strong German core dominates the European Network of Co-Patenting.

This, however, is not a structural problem for an analysis that aims to make a contribution to an improved operationalisation of proximity. While the fact that the results reflect a somewhat unipolar economic structure may limit the possibility for worldwide generalisations, to do so is not the main aim of this paper. In any case, the unipolarity of European patent activity is a fact that will show up regardless from which perspective patent activities are analysed, as Germany accounts for more than 40% of annual EPO applications. The degree of regional concentration is thus certainly not unreasonably higher for co-patent applications than for other application activities, making connectivity a suitable indicator among others.

Network Measures

As the results of the exploratory regression indicate that an approach concentrating on a single measure of geodesic proximity alone may not be able to account for the complexity of the situation several network measures were calculated based on the abovementioned co-patenting matrix to reflect different aspects of centrality and hierarchy (by means of the UCINET software developed by Analytic Technologies).

Within the scope of this paper it is neither possible nor necessary to extensively elaborate on the nature of the selected measures in detail. There is an extensive body of literature from which such information can be obtained (introductory e.g. Wassermann/Faust 1994). Nonetheless, a brief description follows below:

- Normalised Freeman Degree Centrality ("nDegree" in later tables): Degree centrality is defined as the number of links incident upon a node. It thus reaches only one step into the network. Hence, degree centrality can be interpreted as the likelihood that the actors on a node get in contact with what is flowing through the network, by means of their contacts to their immediate vicinity. To normalise, degree centrality is divided by the number of other nodes theoretically reachable.
- Normalised Betweenness Centrality ("nBetw"): Betweenness centrality is a more complex measure that indicates to what extent nodes occur on the shortest paths between all other vertices. In brief, betweenness centrality illustrates to what degree information exchanged in the network will likely pass by a certain node or not. Normalized betweenness centrality divides simple betweenness centrality by its maximum value.
- Closeness Centrality ("Close"): is a sophisticated measure of centrality. It is defined as the mean geodesic distance (i.e. "the shortest path") between a node and all other vertices reachable from it. Other than betweenness centrality it thus refers to the degree of effort that on average it takes to connect to information available at other points in the network.
- Normalised Eigenvector Centrality ("nEigen"): Eigenvector centrality is a measure of the importance of a node in a network, variants of which are for example used by internet search engines. It assigns relative scores to all nodes in the network based on the principle that connections to other high-scoring nodes contribute more to the score of the node in question than connections to low-scoring nodes. Implicitly, it thus gives an assessment of the "importance" of a node in a network that mere degree centrality cannot provide (The mathematical formula for its calculation being $\lambda x = A'Ax$, with x as the eigenvector of centrality scores and A as the connectivity matrix. The normalized eigenvector centrality is the scaled eigenvector centrality divided by the maximum difference possible expressed as a percentage).

- Coreness Measures ("Core") reach beyond mere centrality and reflect the attribution of a node to a certain core which is closer to the centre of a core-periphery structure. In a simple way coreness scores of node can for example be computed by pruning connections to all nodes with a degree of less than k from a node and then allocate the respective remaining degree to that node as 'k-coreness'. As a result, only those linkages are accounted for that reach to similarly or better networked nodes so that 'k-coreness' can be roughly interpreted as reflecting connectivity among central nodes. The concept of *Continuous Coreness* applied in this study is based on a more complex vector based approach that, however, incorporates a similar logic.

In short, mere Degree Centrality considers only the immediate vicinity of a node, while more complex measures like Betweenness Centrality and Closeness Centrality take a closer look on its overall position in the network. Eigenvector Centrality and Coreness finally put a stronger emphasis on the "importance" of a node in the network than other measures.

In most cases, the described network measures will be highly correlated, complicating their use as explanatory variables in models. While, from a technical point of view terms such correlation is of cause problematic, this exploratory study follows Bonacich et al. (1998) in that, in a first step, it is possible to take the position that "correlation is not undesirable. All that is necessary is that the two forms of centrality be conceptually different. They need not be orthogonal", even though in the long run a way should be found to deal with the issue.

If not otherwise noted, centrality measures have been calculated on a weighted network (i.e. one that contains information on the strength of links) rather than a dichotomous one (i.e. one that only contains information on the presence of a link), which makes a difference with regard to Degree Centrality, Eigenvector Centrality and Continuous Coreness.

Network Lagged Variable

In addition to the aforementioned network measures, a network lagged variable ("NetLag") was developed, to additionally take into account the extent of knowledge resources that a region is connected to via co-patenting (i.e. as $w_i = \Sigma_i \Sigma_j$ $copat_{ij}$ $pattot_j$). In a sense, it represents a degree measure weighted by the regional innovative activity in the other regions that a region in question is connected to thus enables us to inquire into the issue of whether links really have a "pipeline character". This information on the other regions' attributes cannot be obtained by network measures alone and therefore deserves separate consideration.

Traditional Spillover Measures

Spatially lagged variables ("SpatialLag") were constructed with functionalities of the GeoDa spatial analysis software (Anselin et al. 2004) defining adjacency as discrete (i.e. 1/0) so that possible distance decay is not taken into account in the contiguity matrix. This very simple form of a spatially lagged variable was chosen intentionally, to be able to differentiate between regional spillover based on adjacency and spillovers based on collaborative proximity. Adjacency was defined as a location of the geometric centres of the respective regions within a range of 300km since spillover effects were in the past found to not reach far beyond 250 km (Moreno-Serrano et al. 2005). With this standard procedure, two spatially lagged variables were developed for both patent applications and patent intensity ("pat_l300"; "patpop_l300").

Control Variables

Control variables were obtained using the average of Eurostat figures in the period of 2000 to 2004, for the following attributes:

- human resources in science and technology, core (HRSTC head count "HRHC", HRSTC per capita "HRPC");
- gross expenditure on research and development (GERD in PPS2000 "GERD");
- research intensity (GERD as a % of GDP "GERDpGDP"), and
- business share in research expenditure (BERD as a % of GERD "BERDpGERD").

GERD related figures had to be estimated for Belgium, Greece (from the NUTS 1 level) and the UK (from existing information on BERD, GOVERD and HERD). As data on social conditions is more difficult to obtain and has in prior studies been found to possess only moderate explanatory power (Tappeiner et al. 2008) it was decided to omit such factors from this analysis.

Scope of Dataset

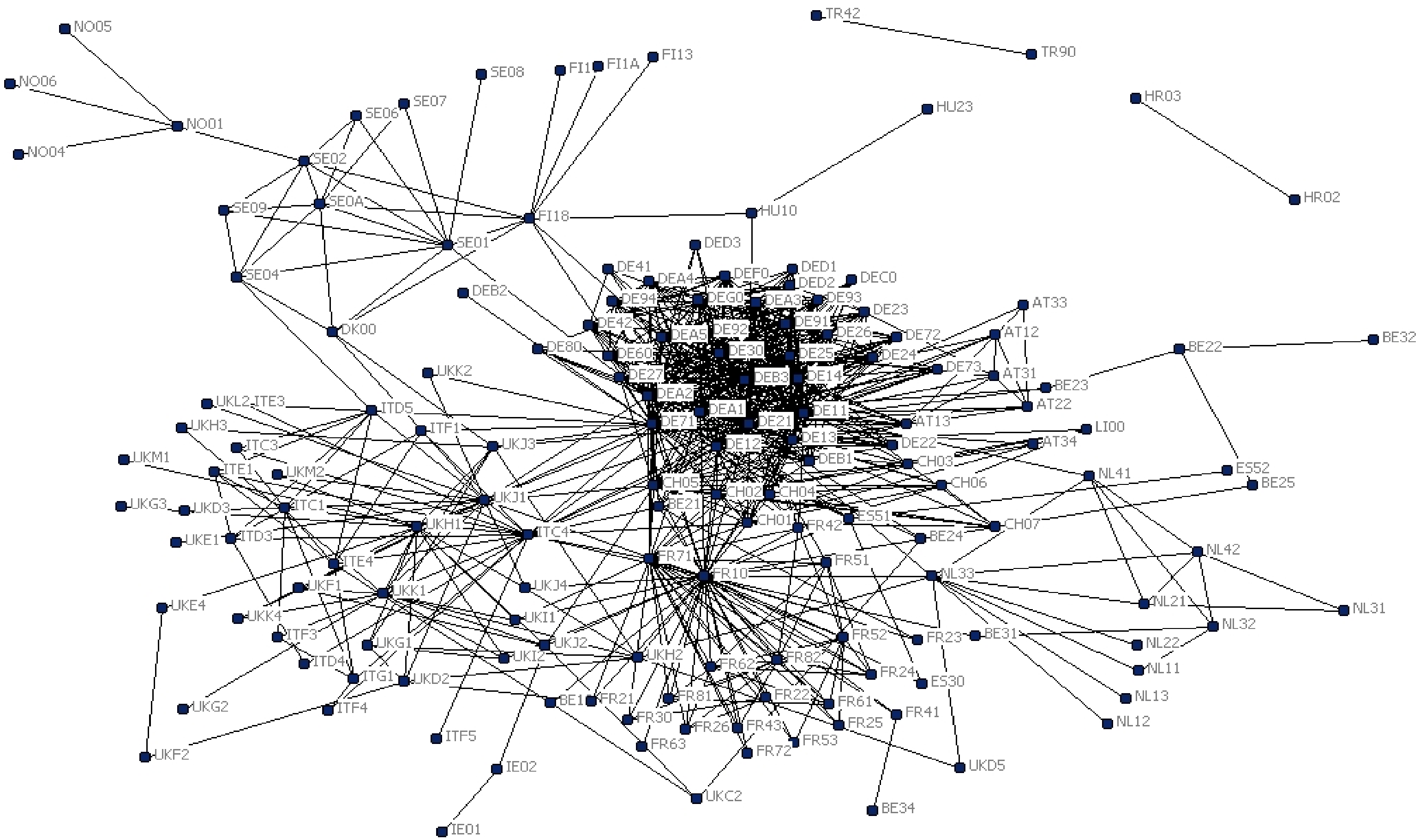
As many control variables are only available in a reliably harmonised form for the NUTS 2 regions of the EU27, it was decided to limit the analysis to the EU27. To avoid the artificial exclusion of determining influences, network measures as well as spatially lagged variables take into account available information for the whole of Europe, i.e. for adjacent activities in or co-patenting with Croatia, Norway, Switzerland and Turkey. Particularly, this was done to avoid distorting the analysis by excluding the effects caused by the significant innovative activities in Switzerland that are at the centre of the network (cf. Figure 1). As a side effect, it helps to avoid statistical problems that would have arisen from the inclusion of explanatory variables that exclusively refer to the connectedness to other cases in the sample.

Table 2: Top-10 EU27 NUTS2 Regions by Network Measure and Rank Order

	nDegree	nBetw	Close	nEigen	Core	pat_I300	patpop_I300	LagNet
1	DE21, 3.185	DE11, 4.036	**FR10**, 73.87	DE21, 50.82	DE21, 0.377	**FI19**, 3985	DE27, 1570	DE21, 27.72
2	DE71, 2.814	DE71, 3.614	DE71, 73.09	DE71, 45.10	DE71, 0.346	**CH06**, 3068	**CH04**, 1569	DE71, 26.62
3	**FR10**, 2.476	DEA1, 3.457	DE21, 71.95	**CH05**, 41.01	**CH05**, 0.279	**CH05**, 2996	**FI19**, 1559	DE11, 19.41
4	**CH05**, 2.346	**FR10**, 3.241	DE12, 71.39	DE11, 37.21	DE11, 0.273	**LI00**, 2995	**AT34**, 1555	DEA1, 18.45
5	DE11, 2.186	DE12, 2.738	DEA1, 70.84	DE13, 34.65	DE12, 0.248	DE26, 2973	**CH06**, 1531	DE12, 18.07
6	DE12, 2.157	DE30, 2.575	DEA2, 70.31	DE12, 34.39	DE13, 0.247	DE27, 2912	DE14, 1527	**FR71**, 17.43
7	DEA1, 1.972	DEA2, 2.525	DE11, 69.77	DEA1, 32.49	DEA1, 0.236	**AT34**, 2907	**CH05**, 1526	DEA2, 17.14
8	DEA2, 1.855	**ITC4**, 2.309	**ITC4**, 68.91	DEA2, 30.50	DEA2, 0.219	**CH04**, 2905	**ITC2**, 1520	DE13, 16.51
9	DEB3, 1.733	DE21, 2.175	**CH05**, 68.73	**CH02**, 27.38	DEB3, 0.184	**FR51**, 2796	**FR42**, 1501	**CH05**, 15.43
10	DE13, 1.681	**UKI1**, 1.976	**CH01**, 68.06	DEB3, 26.31	**CH02**, 0.181	**CH02**, 2751	**CH02**, 1501	DEB3, 14.49

Source: own calculations based on PATSTAT, REGPAT, UCINET

Figure 1: Co-Patenting Network Between European NUTS 2 Regions for 2000-2004



Note: to improve legibility, relations with a value of less than 20 were omitted and vertices having no relations with a value higher than 20 were deleted

Source: PATSTAT, REGPAT, NetDraw

5 Results

Most variables in the model were found to be significantly non-normal, the exception being closeness. To ensure meaningful modelling and reduce artefacts, both dependent and independent variables were submitted to a square root transformation which significantly improved normality. Logarithmic transformation was tested and discarded as an exclusion of cases with zero values substantially reduced the scope of the sample while a logarithmic transformation after adding 1 did not substantially improve normality.

Results A: Total Patent Application Activity

Assumption/Hypothesis A 1:

a) As Table 3 illustrates that, consistent with conceptual deliberations, all selected networking measures do indeed predict total patenting to a substantial degree. However, their explanatory power differs significantly and is strongest for degree centrality. Additionally, Table 4 illustrates that, as predicted, most network measures do indeed correlate strongly so that it seems desirable to define a meaningful sub-set of them for further modelling.

b) Likewise, the network lagged variable is found to substantially correlate with all of the network measures. Its explanatory power is far higher than that of the spatial lag variables. It is somewhat higher than that that of the more complex network measures, however, other than expected, lower than that of degree centrality.

c) Table 5 demonstrates that when all five network measures are included in one model, only degree centrality and betweenness centrality retain a significant specific effect. Given the substantial correlation among them, however, even that appears remarkable. Negative effects of some variables are present, but insignificant. The explanatory power of the overall model (R^2-adj: 0.9052) is scarcely improved by including all variables instead of just Degree Centrality and Betweenness Centrality (R^2-adj: 0.8861). Notably, this includes the network lagged variable. Consequently, only the two most relevant explanatory variables will be retained as representatives for the "network aspect" in the following steps of the analysis.

Assumption/Hypothesis A 2:

a) While the effect attributable to spatial lags is significantly positive, on their own, they have far less explanatory power than both network measures and the network lagged variable.

b) Table 6 illustrates that in a multivariate model with the selected network measure variables spatially lagged variables do not retain a specific effect that substantially improves the model. The effect of the network lagged variable in contrast, remains significant, but turns negative.

Assumption/Hypothesis A 3:

a) Table 7 illustrates that a model based on some key attributes of the regional innovation system is indeed by itself a significant predictor of the total patent application activities in a region. Nonetheless, degree centrality retains a specific effect, when included in the model. Betweenness centrality, in contrast, does not. Remarkably, spatial lagged variables regain their specific effect against degree centrality when additional variables relating to key attributes of the regional innovation system are introduced.

b) A model based on some key attributes of the regional innovation system is improved by the inclusion of the network measures as explanatory variables. The additional consideration of spatially and network lagged variables does not substantially improve the model, although their inclusion does in the absence of network measures.

Results B: Patenting Intensity

When patenting intensity rather than total patent application activity is chosen as a dependent variable, the results are similar, but not identical.

Assumption/Hypothesis B 1:

a) Table 8 illustrates, all selected networking measures do again predict patenting intensity to a substantial degree, even if less so than total patenting activities. As in the first models, their explanatory power differs and is in this case strongest for degree centrality and closeness centrality.

b) Likewise, the explanatory power of the network lagged variable is about equal to that of most complex network measures (with the exception of betweenness centrality), only marginally higher than that of the spatial lag variables but again lower than that of degree centrality.

c) Table 9 demonstrates that when all five network measures are included in one model, all of them retain significant specific effects, some of which are negative. The explanatory power of the overall model (R^2-adj: 0.7145) is scarcely improved by including all variables instead of just degree centrality (R^2-adj: 0.6820). Notably, this includes the network lagged variable. Consequently, these most relevant explanatory variables will be retained as representatives for the "network aspect" in the following steps of the analysis.

Assumption/Hypothesis B 2:

a) The effect attributable to spatial lagged variables is significantly positive. As in the first case, on their own, they do not have as much explanatory power as some network measures or the network lagged variable.

b) Table 10 illustrates that, other than with regard to total patent application activity, spatially lagged variables retain a significant specific effect on patent intensity in a multivariate model which additionally considers network measures and even significantly improve the explanatory power of that model. The effect of the network lagged variable, in contrast, remains insignificant and negative (significantly negative, when both spatially lagged variables and network descriptors are considered).

Assumption/Hypothesis B 3:

a) Table 11 demonstrates that for patent intensity as for total patent application activity a model based on some key attributes of the regional innovation system is a significant predictor of the total inventive activities in a region (although the effects of the individual attributes are different). Nevertheless, both degree centrality and closeness centrality retain their specific effects when included in the model. Likewise, the spatially lagged variable and the network lagged variable maintain their specific effects when additional variables relating to the attributes of the regional innovation system as well as degree centrality and closeness centrality are included in the model.

b) In the case of patent intensity, a model based on some key attributes of the regional innovation system is improved by the inclusion of the network measures as explanatory variables. As in the model for total patent application activity, the additional consideration of spatially and network lagged variables does not substantially improve the model, although their inclusion does in the absence of network measures.

Table 3: Univariate Models for the Effect of Single Network Measures on Total Patent Application Activity

	nDegree	nBetw	Close	nEigen	Core	NetLag	SpatialLag
Coefficient	60.16851	44.50132	34.87012	13.32072	155.5405	.0184929	.71685
Std. Error	1.470663	1.79748	1.456529	.5454159	6.420682	.0006111	.0769723
R^2-adj	0.8782	0.7251	0.7115	0.7196	0.7163	0.7963	0.2681
n=	233	233	233	233	233	235	235

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 4: Correlation between Network Measures, Spatially Lagged Variables and Network Lagged Variables

	lag300_0	NetLag	nDegree	nBetw	Close	nEigen	Core
NetLag	0.5971	1					
nDegree	0.6002	0.9800	1				
nBetw	0.4136	0.8101	0.8591	1			
Close	0.6282	0.8229	0.8750	0.8186	1		
nEigen	0.5787	0.9762	0.9551	0.7814	0.7739	1	
Core	0.5831	0.9723	0.9534	0.7810	0.7740	0.9985	1

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 5: Multivariate Model for the Effect of Network Measures on Total Patent Application Activity

	Coefficient	**Std.-Error**	**p**		**Coefficient**	**Std.-Error**	**p**
nDegree	**89.56698**	**6.883987**	**0.000**	nDegree	**97.87934**	**9.098867**	**0.000**
nBetw	**6.197127**	**2.176208**	**0.005**	nBetw	**5.651241**	**2.206773**	**0.011**
Close	-2.84555	1.951117	0.146	Close	-2.98618	1.9497	0.127
nEigen	-6.84545	5.929709	0.250	nEigen	-3.27070	6.449773	0.613
Core	-15.9789	67.36252	0.813	Core	-41.8561	69.74201	0.549
_cons	16.43268	13.09178	0.211	NetLag	-.004245	.0030468	0.165
				_cons	17.17513	13.07559	0.190
R^2-adj=0.9049, n=233				R^2-adj=0.9052, n=233			

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 6: Multivariate Model for the Effect of Spatially Lagged Variables and Network Lagged Variables on Total Patent Application Activity, Controlling for Key Network Measures

	Model 1	Model 2	Model 3	Model 4
SpatialLag		.043968		.0653079
NetLag			**-.0118296*** **	**-.0122942*** **
nDegree	**50.29883*** **	**48.40945*** **	**90.04757*** **	**88.80241*** **
nBetw	**9.346012*** **	**10.0584*** **	**5.718453***	**6.634121*** **
R^2-adj=, n=	0.8861, 233	0.8863, 233	0.8974, 233	0.8984, 233

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 7: Multivariate Model for the Effect of Key Network Measures, Network Lagged Variables and Spatially Lagged Variables on Total Patent Application Activity, Controlling for Regional Attributes

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
nDegree				**39.89086*** **	**34.88689*** **	**72.68222*** **
nBetw				.9799539	1.798655	.0442167
NetLag			**.010602*** **			**-.0094902*** **
SpatialLag		**.3839757*** **			**.124407** **	
HRHC	**-1.312654*** **	-.4692735	**-.8895606*** **	**-.7041545** **	**-.5067439* **	**-.5835811* **
HRPC	2.588901	-.7890867	1.19702	.5869294	-.3188598	.3026814
GERD	**1.696241*** **	**1.436863*** **	**1.059717*** **	**.7997524*** **	**.8064468*** **	**.6727626*** **
GERDpGDP	**-.9057091** **	**-.8472389** **	**-.7719558** **	**-.6884204** **	**-.6911049** **	**-.6399384** **
BERDpGERD	**1.115638*** **	**.478189* **	.1977896	**.4262242** **	.2956563	.700554
R^2-adj=, n=	0.8008, 226	0.8527, 226	0.8998, 226	0.9185, 226	0.9222, 226	0.9232, 226

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 8: Univariate Models for the Effect of Single Network Measures on Patent Intensity

	nDegree	nBetw	Close	nEigen	Core	NetLag	SpatialLag
Coefficient	30.59093	20.90285	19.04875	6.985383	82.10762	.0094551	.8520638
Std. Error	1.369965	1.425443	.940146	.3780897	4.396325	.0004769	.0500976
R^2-adj	0.6820	0.4799	0.6384	0.5946	0.5999	0.6263	0.5520
n=	233	233	233	233	233	235	235

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 9: Multivariate Model for the Effect of Network Measures on Patent Intensity

	Coefficient	**Std.-Error**	**p**		**Coefficient**	**Std.-Error**	**p**
nDegree	**24.88442**	**6.875307**	**0.000**	**nDegree**	**30.95874**	**9.10551**	**0.018**
nBetw	**-4.84860**	**2.173465**	**0.027**	**nBetw**	**-5.24748**	**2.208384**	**0.000**
Close	**8.525704**	**1.948657**	**0.000**	Close	8.422935	1.951123	0.102
nEigen	**-13.2003**	**5.922233**	**0.027**	nEigen	-10.5880	6.454481	0.057
Core	**152.4695**	**67.27759**	**0.024**	Core	133.5595	69.79292	0.310
_cons	-50.7345	13.07527	0.000	NetLag	**-.003102**	**.003049**	**0.001**
				_cons	-50.1920	13.08513	0.000
R^2-adj=0.7145, n=233				R^2-adj=0.7145, n=233			

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 10: Multivariate Model for the Effect of Spatially Lagged Variables and Network Lagged Variables on Patent Intensity, Controlling for Key Network Measures

	Model 1	Model 2	Model 3	Model 4
SpatialLag		**.25034*** **		**.4336249*** **
NetLag			-.0016269	**-.0047857***
nDegree	**20.008*** **	**17.874*** **	**25.5988** **	**33.42891*** **
Close	**7.783*** **	**4.591** **	**7.304068*** **	2.408981
R²-adj=, n=	0.7059, 233	0.7703, 233	0.7053, 233	0.7884, 233

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 11: Multivariate Model for the Effect of Key Network Measures, Network Lagged Variables and Spatially Lagged Variables on Total Patent Application Activity, Controlling for Regional Attributes

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
nDegree				**21.005*** **	**17.944*** **	**53.647*** **
Close				**5.262** **	2.127	**3.834***
NetLag			**.00674*** **			**-.0092*** **
SpatialLag		**.49625*** **			**.25878*** **	
HRHC	**-1.514*** **	**-.70801** **	**-1.245*** **	**-1.128*** **	**-.7936*** **	**-1.014*** **
HRPC	**5.1989*** **	**2.5093** **	**4.313*** **	**3.1574*** **	**2.512** **	**3.053*** **
GERD	**.68772*** **	**.41029*** **	**.28279** **	**.10051**	**.09861**	**-.02982**
GERDpGDP	**.48106***	**.54692** **	**.56614** **	**.53040** **	**.58545*** **	**.60461*** **
BERDpGERD	**.89755*** **	**.41328** **	**.31367***	**.51326*** **	**.32890** **	**.75887*** **
R²-adj=, n=	0.6703, 226	0.7922, 226	0.7904, 226	0.8329, 226	0.8536, 226	0.8457, 226

Source: own calculations based on PATSTAT, REGPAT, UCINET

Additional Consideration: Diversity vs. Intensity of Links

So far, all assumptions have been assessed based on findings for a weighted network, i.e. for one that takes into account the strength of linkages. To finish, the paper aims to briefly address the question whether similar results are obtained when the analysis is based on a dichotomous network that only accounts for the fact of linkages between regions. In such a network, degree centrality e.g. does not denote the number of co-patenting links incident upon a node (irrespective of source) but the number of regions that a region is connected to via co-patenting.

Firstly, with regard to the centre-periphery structure illustrated by Figure 1, it seems expectable that a certain form of hub-and-spoke structure will be reflected in the findings, i.e. that regions with a high level of patent application activity will be connected to more regions than others.

Secondly, since the number of other regions that a region is connected to says much more about the diversity than about the intensity of knowledge flows it seems plausible to suspect that it may be somewhat less of a suitable predictor of patenting intensity in a region.

Thirdly, if the assumptions from the conceptual section are to be considered generalisable to a degree, it appears likely that network measures based on a weighted network maintain their explanatory power, even when controlling for the overall hub-and-spoke structure of the factual EU patent network based on network measures derived from a dichotomous network.

The corresponding models are displayed in Table 12 to Table 15.

In summary, the findings are consistent with the notion of a hub-and-spoke system that underlies the flows of knowledge in the European system. The independent significance of the effects caused by different network variables indicates a complex hierarchical structure. Interestingly, a key position in the network in terms of eigenvector centrality is, ceteris paribus, associated with a lower absolute level of activity than a non-key position (cf. Table 12 and Table 14).

Even though network measures do not display individually significant effects when taken together their effects are all significant by themselves and can account for about the same degree of variance in patent intensity than those based on a weighted network (for eigenvector centrality and coreness the share is even higher). Apparently, and somewhat contrary to expectations, a hub-position is also important with regard to patent intensity (cf. Table 13 and Table 14).

Finally, as expected, the effects of intensity and diversity can be considered mutually independent, both with regard to patent activity and patent intensity. Also, their joint consideration improves the explanatory power of the model.

Table 12: Univariate Models for the Effect of Dichotomous Network Measures on Total Patent Application Activity

	nDegree	nBetw	Close	nEigen	Core
Coefficient	9.672641***	44.25763***	34.87009***	16.5677***	198.863***
Std. Error	.3971908	1.792711	1.456547	.7699451	9.135755
R^2-adj	0.7185	0.7240	0.7115	0.6657	0.6708
n=	233	233	233	233	233

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 13: Univariate Models for the Effect of Dichotomous Network Measures on Patent Intensity

	nDegree	nBetw	Close	nEigen	Core
Coefficient	5.369968***	20.78034	19.04927	9.49764	113.1537
Std. Error	.2494432	1.420275	.9401078	.4488761	5.405104
R^2-adj	0.6659	0.4787	0.6384	0.6582	0.6533
n=	233	233	233	233	233

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 14: Multivariate Model for the Effect of Network Measures derived from a Dichotomous Network (DN)

Total Applications	Coefficient	Std.-Error	p	Patent Intensity	Coefficient	Std.-Error	p
nDegree	**26.75768**	**4.954161**	**0.000**	nDegree	1.761576	3.825286	0.646
nBetw	**11.02856**	**3.721391**	**0.003**	nBetw	3.728719	2.87342	0.196
Close	**14.09332**	**5.202243**	**0.007**	Close	1.333711	4.016839	0.740
nEigen	**-44.89594**	**10.65855**	**0.000**	nEigen	6.479185	8.229848	0.432
Core	48.72002	78.91892	0.538	Core	-22.3448	60.93615	0.714
_cons	-97.53195	32.32521	0.003	_cons	-12.12409	24.95946	0.628
R^2-adj=0.8124, n=233				R^2-adj=0.6635, n=233			

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 15: Effect of Degree Centrality on Total Inventive Activity, Controlling for Dichotomous Network Degree Centrality

Total Applications	Coefficient	Std.-Error	p	Patent Intensity	Coefficient	Std.-Error	p
nDegree	**54.11379**	**3.05676**	**0.000**	nDegree	**17.67589**	**2.71078**	**0.000**
nDegree_D	**1.22368**	**.5429949**	**0.025**	nDegree_D	**2.610175**	**.481536**	**0.000**
_cons	-2.936017	1.468746	0.047	_cons	-.0560693	1.302506	0.966
R^2-adj= 0.8803, n=233				R^2-adj= 0.7168, n=233			

Source: own calculations based on PATSTAT, REGPAT, UCINET

6 Discussion

The results have demonstrated that a region's connectedness in the network of collaborative efforts that result in patent applications is intricately related to both local inventive activities and patent intensity. Overall, the findings of this paper are thus in line with the proximity debate and numerous qualitative studies and conceptual propositions in economic geography. In that sense, it has demonstrated that when controlling for co-operative proximity through network measures the effect of geographical proximity remains visible. In the model for patent intensity it even remains significant. As suspected in the literature, both the immediate local environment and the co-operation-based connectedness to other, geographically more distant, centres of innovative activity seem to matter for the flow of applied knowledge that fuel the local process of knowledge generation. In terms of explanatory power, however, co-operative proximity has resulted as the dominant factor with regard to both patent intensity and total inventive activity. Likewise, under controls for key attributes of the regional innovation system, spatially lagged variables based on geographic proximity alone improve the model to a higher extent when the model does not additionally control for co-operative proximity.

An important secondary finding is that with regard to both total patent application activity and patent intensity the plain number of linkages to other regions in the European co-patenting network results as the most relevant predictor.

Firstly, a network lagged variable that takes into account the amount of innovative activity that a region connects to does not yield higher explanatory value than degree normalised degree centrality. Instead, when controlling for the plain number of co-patenting relations incident upon the region (degree centrality) its effect becomes negative. In summary, it thus appears that the number of co-operative links (degree centrality) plays a more important role than the extent of the pools of knowledge to which they connect (network lagged variable). This finding is somewhat at odds with the notion of co-operative links as "pipelines" for interregional knowledge flows (Bathelt et al. 2004). Also, it implies that among regions with a similar amount of linkages to other places those that on average connect to less important nodes will display higher innovative activity. Figure 1 suggests that this may reflect a hierarchical structure of co-patenting relations in many countries rather than a dense inter-national network of excellence among the best.

In a similar manner, the lower predictive power of more complex network measures indicates that mediated co-operative proximity to regions more than "one step away" in the co-patenting network is not too relevant a factor of influence. This finding does not change substantially when network measures are derived from a dichotomous network. Similarly, two attempts to find different results by limiting the analysis to co-patenting networks in the chemical and the pharmaceutical sector (as defined by IPC classes) yielded very comparable findings rather than indicating a higher relevance of more complex forms of connectedness (cf. Tables in Annex, analysis at NUTS 1 level). Possibly, this is due to the fact that there is no time dimension in this analysis. Knowledge flows through the network needed to be controlled for temporal succession, i.e. collaborations needed to be subsequent to each other to pass on information (Singh 2005). Nevertheless, it appears worth noting that with regard to absolute patent application activity it seems to be of higher relevance to which degree regions are mediators "between" other regions, whereas with regard to patent intensity it seems to be more important how "close" they are to all other regions. Also it appears noteworthy that (controlling for degree centrality) the finding the closeness centrality is important for patent intensity seems to be more robust than the finding that betweenness centrality is important for total inventive activity.

In general, however, that fact that collaborative proximity in patenting is such a good predictor in statistical terms should not be misinterpreted as direct causality. As a substantial degree of the variance in patent activity and patenting intensity can also be captured by a model solely based on key attributes of the local innovation system the high degree of 'explanatory power' of the network measures in the univariate models should be read with caution. As the results of the first exploratory regression (Table 1) suggest the high level of innovative activities in some regions will by itself provide the basis for a high degree of integration in terms of co-patenting. Although the analysis in this paper is based on the assumption that networkedness is indeed among the *causative* factors of innovative activity in a region, it does not aim to deny these structural effects. Since the network which is the basis of this study is characterised by monocentricity and there is a high degree of correlation between patent intensity and absolute number of patent applications in a region, the results do not yield themselves easily to a theoretical generalisation. They do, however, provide a valid description of the current relations between the different forms of proximity considered *with regard to application oriented codified knowledge in the European Union between 2000 and 2004*.

In the opinion of the author, the results clearly indicate that, under these framework conditions, causal effects could be attributed to collaborative proximity and spatial proximity even when controlling for key attributes of the local innovation system (i.e. size and structure) under study. Also, their extent could still be found to matter when controlling for structural characteristics by means of measures derived from a dichotomous network. There are thus indications that, all else equal, better inter-regional networkedness as well as adjacency to other innovative regions improve the absolute amount of patent applications and innovative intensity in both leading and lagging regions. While based on this study it is not possible to prove that these findings are not to a degree idiosyncratic there have not been obvious indications that they were, either. Until future research yields complementary different results under other framework conditions or for other aspects of knowledge (e.g. implicit knowledge, non application oriented knowledge) its findings can be considered generalisable to a degree.

7 Conclusions

In conclusion, this brief study has demonstrated how an attempt to account for those knowledge spillovers based on co-operative rather than spatial proximity can be grounded in the conceptual literature and highlighted that there is a lot of conceptual and empirical ground to be covered to contest overly simple notions of regional spillovers in an informed manner through quantitative studies based on network analysis.

Possibly, the findings of the above analysis have to some degree raised the reader's scepticism since they can at first sight be read as demonstrating nothing but the fact that regions with high patenting activities and high patent intensity are better networked than others and that given the structure of the co-patenting network illustrated in Figure

1, this does not come as a surprise. However, the clarity of the effects found under all sorts of controls strongly suggests that inter-regional connectedness does indeed play a substantial role in the European environment and cannot be reduced to the reflection of unknown third factors.

Thus, the analysis has resulted in three main findings:

Firstly, it has provided new evidence for the debate on the role of collaborative proximity and inter-regional spillovers. It has demonstrated that an approach controlling for both regional attributes and non-spatial proximity allows us to put spatial spillovers in perspective. In the future it should allow us come to improved assessments of the issue by including an important explanatory variable so far omitted.

Secondly, while the results have indeed supported some common points of critique raised against the use of spatially lagged variables they have also supported the notion that spatial spillovers matter – as one part of a more complex process. Apparently, knowledge spillovers based on spatial proximity are indeed a determinant for regional knowledge generation.

Thirdly, interesting secondary findings have resulted, such as that that models based on measures of mediated co-operative closeness (closeness centrality, betweenness centrality) or the amount of innovative activity in a region that a link connects to (network lagged variable) yield lower explanatory power than those based on the mere extent of linkages (degree centrality). Apparently, knowledge does not easily spill over more than one link in the patenting network to a sufficient extent to detect a generalisable effect. Also the strongest effect of collaborative linkages seems to result from the collaborative effort itself rather than from the "pipeline" to other pools of knowledge that it establishes.

Having started off with a critique of the coarseness of some current approaches, however, it is important not to rush to conclusions on what is, for the moment, preliminary evidence. This paper was aimed to be and is of an exploratory nature. While a co-patenting network gives a solid indication of the co-operative links that may enable flows of application oriented knowledge it remains imperfect. Even though the results could be reproduced for co-patenting network graphs built for two selected technological fields, one cannot be sure to what extent the specific effects of more complex network measures can be considered robust.

To improve our understanding of the effects of co-operative proximity on innovative processes, further contributions need to be made. Given the multidimensionality of knowledge flows research efforts should not remain limited to co-patent applications when trying to operationalise collaborative proximity but be extended to proximity evidenced by joint publications. Since numbers in co-publication networks are typically higher, such an analysis could allow the inclusion of a temporal dimension which so far remains missing from this approach. Also, interrelation with the network of co-patenting could be investigated.

Acknowledgements

I would like to thank Knut Koschatzky for valuable comments to a first draft of this paper. Similarly, I acknowledge the support of my colleague Nicolai Mallig, who, as a trained developer of databases implemented PATSTAT, REGPAT and queried with ease a co-patenting matrix from an environment that would have been far more difficult for the author to master. Any interpretations of the results remain of course entirely within the responsibility of the author.

References

Amin, A./Cohendet, P. (1999): Learning and adaptation in decentralised business networks, *Environment and Planning D: Society and Space,* 17, 87-104.

Anselin et al. (2004): GeoDa spatial analysis software. Online: http://geodacenter.asu.edu/.

Anselin, L. (1988): *Spatial econometrics: methods and models*. London: Kluwer.

Anselin, L./Varga, A./Acs, Z. (1997): Local Geographic Spillovers between University Research and High Technology Innovations, *Journal of Urban Economics,* 42, 422-448.

Asheim, B./Coenen, L. (2006): Contextualising Regional Innovation Systems in a Globalising Learning Economy: On Knowledge Bases and Institutional Frameworks, *Journal of Technology Transfer,* 31, 163-173.

Bathelt, H./Malmberg, A./Maskell, P. (2004): Clusters and Knowledge: Local Buzz, Global Pipelines and the Process of Knowledge Creation, *Progress in Human Geography,* 28, 31-56.

Blind, K./Edler, J./Frietsch, R./Schmoch, U. (2006): Motives to Patent: Evidence from Germany, *Research Policy,* 35, 655-672.

Bonacich, P./Oliver, A./Snijders, T.A.B. (1998): Controlling for size in centrality scores, *Social Networks,* 20, 135-141.

Boschma, R.A. (2005): Proximity and Innovation: A Critical Assessment, *Regional Studies,* 39, 61-74.

Boschma, R.A./Lambooy, J.G. (2002): Knowledge, market structure and economic coordination: dynamics of industrial districts, *Growth and Change,* 33, 391-311.

Boschma, R.A./ter Wal, A.L.J. (2007): Knowledge networks and innovative performance in an industrial district: the case of a footwear district in Southern Italy, *Industrial Innovation,* 14, 177-199.

Bottazzi, L./Peri, G. (2003): Innovation and spillovers in regions: Evidence from European patent data, *European Economic Review,* 47, 687-710.

Breschi, S./Lissoni, F. (2001): Knowledge Spillovers and Local Innovation Systems: A Critical Survey, *Industrial and Corporate Change,* 10, 975-1005.

Bunnell, T./Coe, N. (2001): Spaces and scales of innovation, *Progress in Human Geography,* 25, 569-589.

Castells, M. (1996): *The Rise of the Network Society, The Information Age: Economy, Society and Culture Vol. I*. Cambridge, MA; Oxford, UK: Blackwell.

Castells, M. (2002): Local and global: Cities in the network society, *Tijdschrift voor Economische en Sociale Geografie,* 93, 548-558.

Cohen, W.M./Levinthal, D. (1990): Absorptive Capacity: A new perspective on learning and innovation, *Administration Science Quarterly,* 35, 128-152.

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

Cooke, P./Morgan, K. (1998): *The Associational Economy. Firms, Regions, and Innovation*. Oxford: Oxford University Press.

Cooke, P./Heidenreich, M./Braczyk, H.-J. (eds.) (2004): *Regional Innovation Systems: the role of governance in a globalized world*, Second Edition. London, New York: Routledge.

Crescenzi, R./Rodriguez-Pose, A./Storper, M. (2007): The territorial dynamics of innovation: a Europe-United States comperative analysis, *Journal of Economic Geography,* 7, 673-709.

Cumbers, A./Mackinnon, D./Chapman, K. (2003): Innovation, collaboration, and learning in regional clusters: A study of SMEs in the Aberdeen oil complex, *Environment and Planning A,* 35, 1689-1706.

European Commission (2008): *Challenging Europe's Research: Rationales for the European Research Area (ERA). Report of the ERA Expert Group*. Luxembourg: European Commission, Directorate-General for Research, Directorate C - European Research Area: Knowledge-based economy, Unit C1 - European Research Area Policy.

Eurostat (2008): Data Explorer. Online: http://ec.europa.eu/eurostat/.

Gallié, E.-P. (2009): Is Geographical Proximity Necessary for Knowledge Spillovers within a Cooperative Technological Network? The Case of the French Biotechnology Sector, *Regional Studies,* 43, 33-42.

Gilly, J.P./Torre, A. (2000): Proximity relations. Elements for an analytical framework. In: Green, M.B./McNaughton, R.B. (eds.): *Aldershot Industrial Networks and Proximity*: Ashgate.

Granovetter, M. (1973): The Strength of Weak Ties, *American Journal of Sociology,* 78, 1360-1380.

Granovetter, M.S. (1985): Economic Action and Social Structure: The Problem of Embeddedness, *American Journal of Sociology,* 91, 481-510.

Hinze, S./Schmoch, U. (2004): Opening the black box: analytical approaches and their impact on the outcome of statistical patent analyses. In: Moed, H.F./Glänzel, W./Schmoch, U. (eds.): *Handbook of Quantitative Science and Technology Research, The Use of Publication and Patent Statistics in Studies on S&T Systems*. Dordrecht: Kluwer Academic Publishers, 215-235.

Humphrey, J./Schmitz, H. (2002): How does insertion in global value chains affect upgrading in industrial clusters?, *Regional Studies,* 36, 1017-1027.

Jaffe, A./Trajtenberg, M./Henderson, R. (1993): Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations, *The Quarterly Journal of Economics,* 108, 577-598.

Karlsson, C./Maier, G./Trippl, M./Siedschlag, I./Owen, R./Murphy, G. (2008): ICT Diffusion, Innovation Systems, Globalisation and Regional Economic Dynamics: Theory and Empirical Evidence (= Working Paper No. 233). Ireland: ESRI.

Kroll, H./Stahlecker, T. (forthcoming): *Europe's Regional Research Systems: Current Trends and Structures*. [Internal Project Report submitted to the Commission of the European Communities, DG RTD, to be published in 2009].

Lagendijk, A./Lorentzen, A. (2007): Proximity, Knowledge and Innovation in Peripheral Regions. On the Intersection between Geographical and Organizational Proximity, *European Planning Studies,* 15, 457-466.

Maillat, D. (1998): Vom 'Industrial District' zum innovativen Milieu: Ein Beitrag zur Analyse der lokalen Produktionssysteme (From industrial networks to innovative milieus: towards an analysis of territorial production systems), *Geographische Zeitschrift,* 86, 1-15.

Maliepaard, E./Oosterom, R. (2006): Death of distance or does proximity still matter? Online: http://socgeo.ruhosting.nl/html/files/geoapp/Werkstukken/Distance.pdf.

Markusen, A. (1999): Fuzzy concepts, scanty evidence, policy distance: The case for rigour and policy relevance in critical regional studies, *Regional Studies,* 33, 869-884.

Moreno-Serrano, R./Paci, R./Usai, S. (2005): Spatial spillovers and innovation activity in European regions, *Environment and Planning,* 37, 1793-1812.

Navarro, M./Gibaja, J.J./Bilbao-Osorio, B./Aguado, R. (2008): *Patterns of innovation in the EU-25 regions: a typology and policy recommendations*. San Sebastian, Paris, Bilbao: Basque Institute of Competitiveness, University of Deusto-ESTE, OECD, University of Deusto-La Comercial.

Nonaka, I. (1991): The Knowledge-Creating Company, *Harvard Business Review,* 69, 96-104.

Nonaka, I./Toyama, R./Nagata, A. (2000): A Firm as a Knowledge-creating Entity: A New Perspective on the Theory of the Firm, *Industrial and Corporate Change,* 9, 1-20.

North, D.C. (1990): *Institutions, Institutional Change and Economic Performance*. Cambridge: Cambridge University Press.

OECD (2008): The OECD REGPAT Database: A Presentation (= STI Working Paper No. 2008/2).

Oinas, P. (1999): Activity-specificity in organizational learning: implications for analysing the role of proximity, *GeoJournal,* 49, 363-372.

Polanyi, K. (1944): *The Great Transformation*. Beacon, Boston.

Polanyi, M. (1967): *The Tacit Dimension*. New York: Anchor Books.

Ponds, R./van Oort, F./Frenken, K. (2006): The Geographical and Institutional Proximity of Scientific Collaboration Networks. Online: http://ideas.repec.org/p/wiw/wiwrsa/ersa06p762.html.

Sassen, S. (2002): Locating cities on global circuits, *Environment and Urbanization,* 14, 13-30.

Schmoch, U. (1997): Indicators and the Relation between Science and Technology, *Scientometrics,* 38, 103-116.

Scott, A.J. (1998): *Regions and the world economy: the coming shape of global production, competition, and political order*. Oxford and New York: Oxford University Press.

Singh, J. (2005): Collaborative Networks as Determinants of Knowledge Diffusion Patterns, *Management Science,* 51, 756-770.

Sörensen, O. (2003): Social networks and industrial geography, *Journal of Evolutionary Economics,* 13, 513-527.

Tappeiner, G./Hauser, C./Walde, J. (2008): Regional knowledge spillovers: Fact or artifact?, *Research Policy,* 37, 861-874.

Taylor, P.J./Hoyler, M. (2000): The spatial order of European Cities under conditinos of contemporary globalisation, *Tijdschrift voor Economische en Sociale Geografie,* 91, 176-189.

Taylor, P.J. (2004): Is there a Europe of cities? World cities and the limitations of geographical scale analysis, *Scale and Geographic Inquiry: Nature, Society, and Method,* 213-235.

ter Wal, A.L.J./Boschma, R.A. (2009): Applying Social Network Analysis in Economic Geography: Framing some key analytic issues, *Annals of Regional Science,* 43.

Vence-Deza, X./Gonzáles-López, M. (2008): Regional Concentration of the Knowledge-based Economy in the EU: Towards a Renewed Oligocentric Model?, *European Planning Studies,* 16, 557-578.

Verspagen, B. (2007): The Spatial Hierarchy of technological Change and Economic Development in Europe (= UNU-MERIT WP #2007-012).

Viotti, E. (2002): National Learning Systems: A new approach on technical change in late industrializing economies and evidences from the cases of Brazil, *Technological Forecasting and Social Change,* 69, 653-680.

Wassermann, S./Faust, K. (1994): *Social Network Analysis. Methods and Applications*. Cambridge: Cambridge University Press.

Annex

Table 16: Effects in a one-technology network (basic chemicals, paints, soaps, petroleum products, ISI 19: 09)

	nDegree	nBetw	Close	nEigen	Core
Coefficient	8.231891	4.419835	6.14905	2.090284	24.66175
Std. Error	.5563625	.6184216	.5087483	.1741451	2.207106
R²-adj	0.7170	0.3680	0.6278	0.6246	0.5902
n=	87	87	87	87	87

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 17: Effects in a one-technology network (pharmaceuticals, ISI 19: 12)

	nDegree	nBetw	Close	nEigen	Core
Coefficient	7.846425	5.292961	11.68861	1.883569	22.03545
Std. Error	.587696	.585339	.9313278	.1809807	2.221908
R²-adj	0.6733	0.4843	0.6481	0.5551	0.5310
n=	87	87	86	87	87

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 18: Effects on total inventive activity in one-technology networks

ISI 19: **9**	**Coefficient**	**Std.-Error**	**p**	ISI 19: **12**	**Coefficient**	**Std.-Error**	**p**
nDegree	24.49197	2.684505	0.000	nDegree	29.35812	3.447602	0.000
nBetw	2.128263	.8565107	0.015	nBetw	3.728703	1.068375	0.001
Close	1.202637	1.299495	0.357	Close	2.019832	2.670808	0.452
nEigen	-2.64837	1.403533	0.063	nEigen	-2.92166	1.402875	0.040
Core	23.85685	15.07539	0.117	Core	3.059533	15.17309	0.841
_cons	-8.64349	8.79999	0.329	_cons	-12.9773	15.26229	0.398
R²-adj=0.9516, n=87				R²-adj=0.9387, n=86			

Source: own calculations based on PATSTAT, REGPAT, UCINET

Table 19: Effects on patent intensity in one-technology networks

ISI 19: **9**	**Coefficient**	**Std.-Error**	**p**	ISI 19: **12**	**Coefficient**	**Std.-Error**	**p**
nDegree	5.324583	2.293461	0.023	nDegree	4.735019	2.812851	0.096
nBetw	-1.94522	.7317454	0.009	nBetw	-.620004	.8716723	0.479
Close	3.293716	1.110202	0.004	Close	6.490835	2.179075	0.004
nEigen	.3291611	1.199085	0.784	nEigen	-.350469	1.144586	0.760
Core	.6763742	12.8794	0.958	Core	4.274235	12.37951	0.731
_cons	-20.4098	7.518122	0.008	_cons	-35.3609	12.45229	0.006
R²-adj=0.7396, n=87				R²-adj=0.6947, n=86			

Source: own calculations based on PATSTAT, REGPAT, UCINET

The series "Working Papers Firms and Region" presents research work of the Competence Center "Policy and Regions" of Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), Karlsruhe, Germany.

No.	Authors	Title
R2/2009	Henning Kroll	Spillovers and Proximity in Perspective A Network Approach to Improving the Operationalisation of Proximity
R1/2009	Henning Kroll	The Regional Development of Science and Innovation in China – A Brief Review of Current Evidence on Matches and Mismatches –
R3/2008	Arlette Jappe-Heinze Elisabeth Baier Henning Kroll	Clusterpolitik: Kriterien für die Evaluation von regionalen Clusterinitiativen
R2/2008	Arlette Jappe-Heinze Knut Koschatzky	The spatial embeddedness of multinational enterprises' research activity A bibliometric analysis
R1/2008	David Doloreux Andrea Zenker Emmanuel Muller	Services à forte intensité de connaissances, contexte régional et comportements d'innovation: une comparaison internationale
U1/2007	Emmanuel Muller David Doloreux	The key dimensions of knowledge-intensive business services (KIBS) analysis: a decade of evolution
R1/2007	Knut Koschatzky Vivien Lo	Methodological framework for cluster analyses
U1/2006	Björn Wolf	Empirische Untersuchung zu den Einflussfaktoren der Finanzierungsprobleme junger Unternehmen in Deutschland und deren Auswirkungen auf die Wirtschaftpolitik
R1/2006	Emmanuel Muller Arlette Jappe Jean-Alain Héraud Andrea Zenker	A regional typology of innovation capacities in New Member States & Candidate Countries
R1/2005	Björn Wolf Birgit Ossenkopf	Kapitalschonende Entwicklungswege – Ansätze zur Lösung der Finanzierungsprobleme junger innovativer Unternehmen
R2/2004	Thomas Stahlecker Knut Koschatzky	On the significance of geographical proximity for the structure and development of newly founded knowledge-intensive business service firms

No.	Authors	Title
R1/2004	Thomas Stahlecker Andreas Koch	On the Significance of Economic Structure and Regional Innovation Systems for the Foundation of Knowledge-Intensive Business Services A Comparative Study in Bremen, Munich, and Stuttgart, Germany
R1/2003	Bodo Kubartz	Wirtschaftliche, soziale und geographische Aspekte in Innovationsnetzwerken – Eine Untersuchung des Nähekonzeptes am Beispiel von Forschungs- und Entwicklungsdienstleistern
R2/2002	Knut Koschatzky	Innovationsorientierte Regionalentwicklungsstrategien: Konzepte zur regionalen Technik- und Innovationsförderung
R1/2002	Ralph W. Bruns Jens Görisch	Unternehmensgründungen aus Hochschulen im regionalen Kontext – Gründungsneigung und Mobilitätsbereitschaft von Studierenden
U1/2001	Rana Adib Frank Gagelmann Knut Koschatzky Klaus Preiser Günter Hans Walter	An Integrated Microfinancing Concept for Rural Electrification by Photovoltaics in Developing Countries
R3/2001	Knut Koschatzky	The role of higher education institutions for entrepreneurship stimulation in regional innovation systems – Evidence from the network-oriented "EXIST: Promotion of university-based start-ups" programme in Germany
R2/2001	Emmanuel Muller Andrea Zenker	Business services as actors of knowledge transformation and diffusion: some empirical findings on the role of KIBS in regional and national innovation systems
R1/2001	Knut Koschatzky Casper Merkle Martin Berger Volker Meyer	Innovation und Kooperation bei unternehmensnahen Dienstleistern in Baden, Gironde und Südholland - Ein Vergleich zwischen jungen und alten Betrieben
R2/2000	Ulrike Broß Günter H. Walter	Socio-economic Analysis of North Rhine-Westphalia Joint Research Project INCO-COPERNICUS
R1/2000	Knut Koschatzky	The regionalisation of innovation policy in Germany – Theoretical foundations and recent experience
R4/1999	Knut Koschatzky Ulrike Broß	Struktur und Dynamik von regionalen Innovationsnetzwerken unter Transformationsbedingungen – das Beispiel Slowenien
R3/1999	Emmanuel Muller	There is no territorial fatality! (or how innovation interactions between KIBS and SMEs may modify the development patterns of peripheral regions)

No.	Authors	Title
R2/1999	Knut Koschatzky Andrea Zenker	The Regional Embeddedness of Small Manufacturing and Service Firms: Regional Networking as Knowledge Source for Innovation?
R1/1999	Ulrike Broß Knut Koschatzky Peter Stanovnik	Development and Innovation Potential in the Slovene Manufacturing Industry First analysis of an industrial innovation survey

Address to order (print version):
Fraunhofer Institute for Systems
and Innovation Research
Library
Breslauer Strasse 48
76139 Karlsruhe, Germany
Tel. +49 / 721 / 6809-217 / -219
Fax: +49 / 721 / 689152
e-mail: bibl@isi.fraunhofer.de