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The spatial evolution of innovation networks: a proximity perspective

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Contribution to the Handbook of Evolutionary Economic Geography

1. Introduction

The role of networks in innovation processes has become a key research area in the field of innovation studies over the last decade and a half (Freeman 1991; Powell et al. 1996; Hagedoorn 2002). Not surprisingly, the rapid increase in the number of studies on innovation networks in an inter-disciplinary field as innovation studies has led to a great variety of theories, concepts and methodologies (Ozman 2009). Only recently, geographers have jumped on the empirical study of the spatial dimensions of networks in innovation processes, following the vast literature on national and regional innovation systems developed in the 1990s (Ter Wal and Boschma, 2008). Despite this attention, network analysis is still underdeveloped in the geography of innovation. This is also true for an evolutionary approach to this topic, although attempts have been undertaken (see e.g. Giuliani, 2007; Gluckler, 2007; contributions in this volume by Breschi et al., Cantner and Graf, Giuliani, Gluckler).

Our aim is to propose an evolutionary perspective on the geography of network formation that is firmly grounded in a dynamic proximity framework. Doing so, we link the emerging literatures on network and proximity dynamics. The study on network evolution is still in a premature phase (Powell et al., 2005), though considered crucial for the development of an evolutionary perspective on the geography of innovation networks. Following Boschma (2005), we will present various forms of proximity as alternative driving forces behind network formation. In doing so, we root the proximity concept in an evolutionary approach to the geography of innovation networks. In this chapter, we discuss three topics.

The first topic focuses on explaining the structure of networks. For instance, why are some individuals or networks better connected than others? Do individuals and firms that are geographically proximate show a higher degree of connectivity? We will use ideas obtained from the French school on proximity dynamics (e.g. Rallet 1993; Rallet and Torre, 1999) to explain the formation of innovation networks. They state that other forms of proximity besides geographical proximity may facilitate interactive learning and innovation. In that context, Boschma (2005) has claimed that geographical proximity is neither a necessary nor a sufficient condition for inter-firm learning and innovation. In this chapter, we will present the different forms of proximity as alternative forces driving network formation.

The second topic concentrates on explaining the effects of networks. For instance, does connectivity increase the innovativeness of organizations? And do local or non-local networks affect the performance of organizations (Bathelt et al., 2004)? While a high degree of proximity might be considered a prerequisite to make agents connected, when assessing the effects of network linkages, we argue that proximity between agents does not necessarily increase their innovative performance, and may possibly even harm it (Boschma, 2005; Broekel and Meder, 2008). We will refer to this as the proximity paradox. We claim it depends on the (optimal) level of proximity between agents whether their connection will lead to a higher level of innovative performance or not.

The third topic deals with the long-term dynamics of networks and the changing role of proximity dimensions in the formation and performance of innovation networks. For instance, do networks of innovation become less geographically proximate over time during the course of an industry lifecycle (e.g. Ter Wal, 2009)? And when does the evolution of a network structure show tendencies of path dependence, and why? We argue that the different proximities may induce path dependence in network evolution, and may cause retention in the local network (Gluckler, 2007). We will explain how local network retention might lead to regional lock-in. Last but not least, we argue that a dynamic network approach should account for that fact that the evolution of network structures may, in turn, affect the degree of the different forms of proximity (Menzel, 2008; Ter Wal and Boschma, 2009).

2. Network structure and the proximity concept

A key question in (innovation) network research is to explain the presence or absence of network relations between organizations, or, more generally, the number or strength of relationships between actors in a network. The dependent variable is thus the bilateral relation. The main strategy to explain network structure, then, is to compare the similarity between actors that are linked with the similarity between actors that are not linked. For example, social networks are generally structured along the lines of gender, ethnicity, age and education as people have a bias to make friends of the same sex, ethnicity, age group and education level. Sociologists call similarity in attributes of nodes *homophily*, but we will follow the terminology of *proximity*, which is more common in innovation studies and related areas with a focus on inter-organisational networks (Rallet 1993; Rallet and Torre 1999; Boschma 2005; Lagendijk and Oinas, 2005; Knoben 2007).

Though scholars differ in the definition of proximity and the number of proximity dimensions, we follow Boschma (2005) in his definition of five forms of proximity: cognitive, organisational, social, institutional and geographical proximity. In short, cognitive proximity indicates the extent to which two organisations share the same knowledge base; organisational proximity the extent to which two organisations are under common hierarchical control, social proximity the extent to which members of two organisations have friendly relationships, institutional proximity the extent to which two organisations operate under the same institutions, and geographical proximity the physical distance or travel time separating two organisations. These proximity dimensions will be discussed below in more detail.

We believe the proximity concept is part and parcel of an evolutionary approach. In an evolutionary approach, firms innovative in areas close to their current cognitive capabilities along well-defined technological trajectories (Nelson and Winter, 1982). Their distinctive capabilities also constitute the primary determinants on partner selection in innovation networks. To exchange knowledge and develop innovations, networking firms tend to be close, yet complementary in cognitive/technological space. The concept of proximity in five dimensions as defined by Boschma (2005) can thus be regarded as an extension of the evolutionary approach which focuses on cognitive proximity primarily: proximity is required in some (but not necessarily all) dimensions to get firms connected and to enable interactive learning and innovation among them.

Cognitive proximity

The effective transfer of knowledge and collaboration requires absorptive capacity to identify, interpret and exploit the new knowledge (Cohen and Levinthal, 1990; Nooteboom 1999; 2000). For this reason, the capacity of actors or firms to absorb new knowledge requires cognitive proximity. That is, their own cognitive base should be close enough to the new knowledge in order to communicate, understand and process it successfully. With the notion of cognitive proximity, it is meant that people or firms sharing the same knowledge base and expertise are expected to learn more from each other than if cognitive distance is large. Nooteboom et al. (2007), among others, have demonstrated that cognitive proximity is indeed an important determinant in R&D alliances. It is also visible in patent citations, which have been considered as proxies for knowledge spillovers. For instance, Breschi and Lissoni (2006) found that most patent citations occur within the same 12 digit patent class. Studies focussing on a specific cluster observe that cluster firms perform different roles in knowledge networks because they differ in cognitive terms. Some firms act as hubs, while other cluster firms are poorly connected because they lack the capabilities to understand and exploit external knowledge (Giuliani and Bell, 2005; Boschma and Ter Wal, 2007; Morrison, 2008).

Organizational proximity

Boschma (2005) defined organizational proximity as the extent to which relations are shared in an organizational arrangement, either within an organization, or between organizations. It involves the rate of autonomy and control that can be exerted in organizational arrangements. A continuum is assumed ranging from one extreme of 'on the spot' market, to informal relations between firms (e.g., interlocking corporate boards), to more formal organizational networks (e.g. a joint-venture, franchise), to the other extreme of a hierarchically organized firm (Williamson, 1985). As for cognitive proximity, organizational proximity is believed to be beneficial for establishing innovation networks, because they reduce uncertainty and opportunism. Strong control mechanisms are required to ensure ownership rights and sufficient rewards for own investments in new technology. Markets are poorly equipped to fulfil these tasks, because they tend to generate excessive transaction costs. In addition, formal contracting is almost impossible when it concerns complex and long-term research collaborations in which it is hard to determine and codify what activities will be undertaken, and what kinds of returns will be generated (Nooteboom, 1999).

Social proximity

The notion of social proximity has its roots in the embeddedness literature (Granovetter, 1985; Uzzi 1996). This literature indicates that economic relations are always embedded in a social context and that, in turn, social relations affect economic outcomes. Boschma (2005) defined social proximity in terms of socially embedded relations between agents at the micro-level. Relations between actors are socially embedded when they involve trust that is based on friendship, kinship and experience through repeated interaction. Such relationships carry information about potential partners and thereby increase the probability of organizations to engage in innovation networks. What is more, the perceived risk of conflict is also lower as social proximity adds to trust among organizations. Social proximity also plays a role in informal knowledge exchange between employees affiliated to different organizations.

Breschi and Lissoni (2003, 2006) found that social connectedness between inventors played a significant role in knowledge spillovers. That is, social networks based on personal acquaintances due to common working experiences are important carriers of knowledge exchange based on reciprocity. Agrawal et al. (2006) point out that firms often connect because their employees used to work for the same organization in the past. These findings support the concepts of epistemic communities, invisible colleges and communities of practice. A particular mechanism in which social proximity plays a key role in the formation of new network relations is known as 'closure', which refers to ties that are created when two nodes are introduced to one another by a common third with whom both already have a network relation.

Institutional proximity

Whereas social proximity is defined in terms of socially embedded relations between agents at the micro-level, institutional proximity is associated with institutions at the macro-level. Both formal institutions (as laws) and informal institutions (like cultural norms and values) influence the extent and the way organizations co-ordinate their actions (Hofstede, 1991; Edquist and Johnson, 1997; Hall and Soskice, 2001). As such, institutions are enabling mechanisms that provide stable conditions for interactive learning. A classic study on institutional proximity has been an empirical study on the adoption of German machinery in Canadian firms (Gertler 1995). The problems in using and maintaining the machinery could be related to different macro-institutions. In Germany with long-life employment and on-the-job training, employees had little difficulty in operating a complex machinery, while in Canadian firms, with high turnover of personnel and little intra-firm training, employees had difficulty operating and maintaining the complex machinery. This example shows that inter-firm relationships are often hampered by a lack of institutional proximity between countries (Hall and Soskice, 2001). Another example of a lack of institutional proximity is in university-industry-government or 'triple helix' relationships (Etzkowitz and Leydesdorff 2000), where different key actors operate in different institutional regimes.

Geographical proximity

The final dimension to be distinguished is geographical proximity. There is a strong claim that geographical proximity is a prime mover of network formation despite globalization, implying that a great deal of interactions still takes place between agents that are geographically proximate (see e.g. Weterings, 2005; Hoekman et al. 2009). Once having defined the four other forms of proximity, geographical proximity can be defined in a restricted manner as the physical distance between actors in absolute (e.g. miles) or relative terms (e.g. travel time) (Boschma, 2005). Geographical proximity is beneficial for innovation as effective learning requires face-to-face interaction. Such interaction is easier (and cheaper) to organise when agents are co-located. The relationship between geographical proximity and co-location is not that straightforward though, because they do not necessarily mean the same thing. The need for geographical proximity (or better, face-to-face interactions) may be realized by temporary co-location (bringing agents together by means of fairs, conferences, business meetings, *et cetera*), instead of permanent co-location (Torre and Rallet, 2005; Torre, 2008). In sum, for analytical purposes, it is essential to define geographical proximity in such a restricted manner, and to isolate it from the other dimensions of proximity.

As proximity is an analytical concept, it offers many advantages in theoretical and empirical work explaining the (spatial) structure of networks.

First, one can extend the list of relevant proximity dimensions with any other dimension without changing the meaning of each dimension. For example, linguistic or ethnic proximity can be introduced. Thus, the proximity dimensions are analytically orthogonal even though many dimensions of proximity may empirically turn out to be correlated. Just to give one example, social proximity between two organizations is generally higher for geographically proximate organizations, because friendships are more easily established and maintained over short distances.

Second, by incorporating multiple proximity dimensions in an explanatory framework, one can test what forms of proximity are more crucial for explaining the formation of networks. For example, many networks are geographically localised. One is then tempted to argue that this is the case because of transportation costs. However, if one explains the presence of absence of links using indicators of both geographical proximity and social proximity, one may find that networks are actually based on social proximity and not on geographical proximity. Yet, if firms with a high social proximity are often co-located, it can seem that geographical proximity is underlying the formation of networks. Thus, ideally, one takes into account as many proximity dimensions as possible as to control for all possible reasons that may underlie network formation between organizations.

Third, the analytical nature of proximity concept allows one to understand the interplay between different dimensions. In particular, one can expect proximity dimensions in innovation networks to be substitutes rather than complements (Boschma, 2005). That is to say, to establish a (successful) relation, one is in need of proximity in at least one dimension to manage the uncertainty involved. Being proximate in a second dimension, then, adds relatively little to the probability a link is formed, or the probability that the relation is successful. Making use of patent data, Singh (2005) found that geographical proximity is especially important in the establishment of interdisciplinary research collaboration (when cognitive proximity is low), while inventors working in the same field (i.e. cognitive proximity is high) collaborate on average over longer geographical distances. Making use of publication data, Ponds et al. (2007) found that geographical proximity is especially important in the establishment of university-industry-government relationships (i.e. institutional proximity is low) and less important in university-university collaboration where actors operate under the same institutions (i.e. institutional proximity is high). Agrawal et al. (2006) found that knowledge is transferred between firms in different locations (so geographical proximity is low) by employees that are socially linked due to a shared past. Breschi et al. (in this volume) found similar results when analyzing the social networks of US inventors who are mobile in space. Although inter-regional mobility of inventors is very low, the few inventors who did move between regions often maintained their ties with former co-inventors, providing a channel of knowledge diffusion to their prior location.

3. Network effects on organizational performance

The effect of networks on the performance of organizations is a second key question in (innovation) network research. Generally, the effects of having networks relations are positive. Most studies find a positive relationship between the number of network relations of a firm and its performance (see Ozman, 2009 for an overview). The same holds for informal social networks as, for example, evidenced by the finding that social networks between two people significantly increase the probability of knowledge spillovers (Breschi and Lissoni 2003, 2006). At the more aggregate level of regions in the European Union, the impact of collaboration networks on regional innovative performance has been analysed by explaining the number of patents by knowledge inputs weighted for the number of collaborations existing between the regions. The results show that the collaboration networks between regions indeed provide access for a region to the scientific knowledge in other regions (Maggioni et al. 2007; Hoekman et al. 2008).

The effect of networks on performance has been further elaborated by distinguishing between different types of knowledge. Sorenson et al. (2006) analyzed US patent data and citation rates across proximate and distant actors on three dimensions of proximity: (1) social proximity (concerning distance between inventors in a network of patent collaborators); (2) geographical proximity (spatial distance between inventors); (3) organizational proximity (firm membership). They came to the conclusion that the advantages of being geographically proximate to some knowledge source depend crucially on the nature of the knowledge at hand. With respect to simple knowledge and very complex knowledge, the results show that more close actors are not in a more advantageous position, as compared to more distant actors. Simple knowledge flows equally to actors near and far, while complex knowledge is unlikely to diffuse, no matter how proximate actors are. With knowledge of moderate complexity, however, the outcomes show that more close actors are in a better position to benefit from knowledge diffusion, in contrast to more distant recipients.

However, these results should not be taken to mean that any network relation will have a positive effect. Each network relation comes at a cost, both in its establishment (search, negotiation) and its maintenance (conflict, monitoring). In the context of innovation networks, a particular risk in networking is the risk of involuntary knowledge spillovers through which valuable knowledge leaks to other organizations. Conflicts may arise as well. The main rationale of agent to share information and knowledge is that they expect such favours to be reciprocal. Once an agent persistently fails to reciprocate, the network linkages will become instable, and will not deliver any positive effects. In addition to that, too much proximity between agents in networks may lead to lock-in situations (Boschma, 2005). Excess cognitive proximity reduces the scope for learning (Nooteboom, 2000). Two people or organizations with the same knowledge have little to exchange. Knowledge creation often requires dissimilar, complementary bodies of knowledge, especially in the context of radical innovations. Cognitive proximity also increases the risk of involuntary knowledge spillovers, especially when the new knowledge cannot be fully appropriated. With respect to social proximity, socially embedded relationships may lead to excess loyalty such that an agent put their friends' interests before their own (Uzzi, 1996). Moreover, long-term relationships, or too much commitment may lock members of social networks into established ways of doing things, which may be harmful for learning.

Consequently, one ends up in a paradoxical situation. In Section 2, we have gone at length to explain that a high degree of proximity is considered a prerequisite to make agents connected. However, when assessing the economic effects of networks, we argue that proximity between agents in networks does not necessarily increase their innovative performance, and may even harm it (Boschma, 2005; Broekel and Meder, 2008). We refer to this as the proximity paradox. When incorporating a proximity framework in network analysis, one should therefore make a distinction between the drivers of network formation on the one hand (in which the forms of proximity positively affect the establishment of networks), and the effects of network on innovative performance on the other hand (in which it is uncertain what the effects of proximity on network performance are).

We claim it depends on the level of proximity between agents whether their connection will lead to a higher level of innovative performance or not. The success of a network relation may be related to optimal levels of geographical proximity (Camagni, 1991), social proximity (Uzzi 1996; Fleming et al. 2007), institutional proximity, organizational proximity (Grabher 1993; Grabher and Stark 1997) and cognitive proximity (Nooteboom 2000). When thinking about an optimal level of geographical proximity, this does not mean determining an optimal geographical distance between two agents. Instead, one should think of a balance of local and non-local linkages. Similarly, the optimal social distance consist of a balance between embedded relationships within cliques and strategic 'structural hole' relationships among cliques. For institutional proximity, an optimal level consists of operating simultaneously in different institutional regimes, such as multinationals operating in different countries or high-tech labs cooperating with industry, government and academia. Concerning the optimal level of organizational proximity, loosely coupled networks that consist of weak ties between autonomous agents combine the advantages of organizational flexibility and coordination. The optimal level of cognitive proximity follows from the need to keep some cognitive distance (to stimulate new ideas through recombination) but also secure some cognitive proximity (to enable communication and effective knowledge transfer).

Besides looking for the optimal level of proximity on all dimensions, one can think of other solutions to the proximity paradox. The negative impact of excessive proximity in one dimension on innovative performance may be counteracted by lower levels of proximity in other dimensions. For instance, regions may confront the problem of regional lock-in by having a (related) variety of different technologies in the region (Frenken et al., 2007), or by having loosely coupled networks, as reflected in regional networks consisting of agents with weak ties (Grabher and Stark, 1997). In sum, optimal levels of proximity may enhance network performance, but the location of an optimum along one proximity dimension depends most likely on the location along other proximity dimensions at the same time.

Though the concept of optimal level of proximity balancing pros and cons has become well established (Boschma 2005), to test these propositions empirically is not straightforward. There are two ways to go about this. First, classifying relationships into relations with high and low proximity, one can assess whether a mix of the two types of relationships leads organizations to perform better than organizations relying primarily on relations with low proximity or on relations with high proximity. This methodological strategy was followed by Uzzi (1996) to test the hypothesis of an optimal social proximity, who showed that a mixture of low and high proximity was best for firms. This can also been done in the case of geographical proximity: some have suggested a mixture of local and non-local linkages to be best for firms, and a combination of local buzz and global pipelines to be best for the long-term evolution of clusters (Bathelt et al., 2004). The second strategy is to classify all relations along a continuum and to assess the success of each particular relation separately. Then, by testing its effect and its quadratic effect, one can assess whether an optimal level of proximity exists (the linear effect should then be positive and the quadratic effect should be negative). For example, making use of patent data, Gilsing et al. (2007) assessed the effect of technological distance between firms in alliance networks in high-tech industries on the exploration innovative performance of firms. As expected, they found an inverse U-shaped function between technological distance and exploration.

4. Network dynamics

A key empirical insight from studies on networks, be it on the context of innovation and knowledge production or in other contexts, holds that networks have very pronounced structures (Newman, 2003). We mean with structure that the set of links between nodes in a network is very different from the properties of a random network, i.e. the properties one obtains by randomly connecting nodes to create a network structure. Structured (or 'organised') networks require a true explanation, while random networks can simply be 'explained' stochastically.

Random networks are characterised by two important features. First, the degree distribution follows a normal distribution, where the degree of a node stands for the number of links of a node (where degree stands for the number of links per node). Since a random network is constructed by assigning links between two randomly selected nodes, the degree of nodes will follow a normal distribution. Second, in a random network, there is no clustering: the probability of two nodes being linked is totally independent of whether these two nodes are linked indirectly via a third node. These two properties of random networks – normal degree distribution and absence of clustering – are never observed in social networks or inter-firm networks. Empirically, one typically observes that the degree distribution is skewed with few nodes having a high degree and many nodes having a low degree. Apparently, some nodes are more 'popular' to link with than other nodes. And, one observes that clustering is a very significant phenomenon ("friends of friends are often friends with one another"). That is, many nodes participate in triangle relationships. Yet, some nodes do so much more than other nodes. The extent to which a node is clustered can be indicated by the number of triangles divided by the number of possible triangles.

At the level of single nodes, these observations lead to two questions: (i) how can one explain differences in the degree of nodes, and (ii) how can one explain the clustering of nodes. Below, we discuss these features using the concepts of preferential attachment and closure, respectively. Then, we propose an industry lifecycle perspective on network evolution and regional lock-in.

Preferential attachment

One key conceptual breakthrough in the study of dynamic networks has been the paper by Barabasi and Albert (1999). In this paper, the authors start from the observation that many networks are characterised by scale-free degree distributions where degree stands for node connectivity. They propose a simple growth model in which each time step a new node is added and preferentially attaches itself to the node with the highest degree. More precisely, the probability that a new node attaches itself to an existing node is exactly proportional to the latter's degree. The specification of this mechanism reflects the benefits of linking to nodes with high degree as such 'hubs' provide new nodes with short pathways to many other nodes in the network. Assuming each node attaches to only one existing node, this mechanism leads to a power law distribution with an exponent equal to three.

In reality, most networks have degree distributions that are different from the pure Barabasi-Albert model. In particular, the degree of the best connected nodes is generally less than the model predicts. Indeed, the tendency of firms to connect to highly connected firms is found to be not as strong (Powell et al. 2005; Ter Wal 2009). One explanation holds that firms are limited in the number of network relations they can meaningfully maintain. In the case of inter-firm networks, it is obvious there are limits to the number of partners a firm can maintain (Holme et al., 2004). This implies that well-connected nodes typically refuse proposals for networking and will select only the most beneficial partners (cf. Giuliani 2007). A second reason why the degree distribution is less skewed than one would predict from preferential attachment is that proximity matters. This means that new nodes – even though attracted by the ones with highest connectivity – often connect to nodes with lower degree if these are more proximate in any of the five dimensions we outlined before. Consider, for example, geographical proximity. A company may opt to collaborate locally to save on travel time and transportation costs, even though companies with the highest connectivity are located in other countries. The preferential attachment model can be easily adapted to incorporate this effect of proximity by assuming that the probability of a node linking to an existing node is not only dependent on the latter's degree but also on the geographical proximity between them (Guimera and Amaral 2004). The same reasoning holds for other forms of proximity. Depending on the benefits of proximity, such a constraint yields different network structures ranging from very skewed degree distributions and low clustering as in the original Barabasi-Albert model when overcoming distance (in whatever dimension) is cheap, to networks with a normal degree distribution and a high clustering as in small worlds (Watts and Strogatz 1998; Zhang et al. 2004) when overcoming distance is rather expensive, to an empty network where any relation is just too expensive to establish.

Closure

Another driving force of network formation is closure. In many instances, new network relations follow from existing relations as two actors are introduced to other another by a third actor which whom both already have a relation. The probability of the two forming a relation who already relate to a common third is expected to be much higher than the probability of two actors forming a relation who do not relate to a common third. The establishment of such triangle relationships is called 'closure' and such closure mechanism will increase the degree of clustering (in a network sense) over time. The reason for closure to be common is twofold: (i) each actor can be informed by the common third about the properties of the other (which knowledge does it possess) and trustworthiness of the other, and (ii) once the relationship is formed each actor has less incentive to behave opportunistically because of loss of reputation regarding the common third.

Note here that the role of social proximity in the formation of network links relates to the concept of closure. Viewing social proximity between two actors as the inverse of geodesic distance (network distance) in a network, closure simply means that if two actors have a social distance of two, they have a higher probability of getting connected. More generally, one expects the probability of a link to be formed to decrease with an increase in geodesic distance between two actors. Dynamically, this means that one expects the social proximity in networks to increase over time.

One hypothesis that has been analysed in a study by Ter Wal (2009) holds that closure in particularly relevant as a mechanism of network formation in exploitation contexts, while it is less important in exploration contexts. The reasoning underlying this hypothesis holds that closure is a way to find a new partner through an existing trusted partner, so that the collaboration with the new partner is embedded in the common relationship with the third actor. As a result, the partners in the new collaboration will have less incentive to behave opportunistically as they risk to jeopardize their relation with the third actor. To avoid opportunistic behaviour is especially important in the exploitation phase of an industry during which knowledge becomes more codified and is transformed in commercial products and services and, consequently, trust in partners is most important. And, logically, a formation of a new network relation is more likely, the more two actors have already partners in common. Studying the evolution of co-inventor networks in the German biotech industry in the period 1970-1995, Ter Wal (2009) found that closure was indeed a key factor driving network formation. As expected, closure became also more important over time as a driver of network formation with the biotech sector evolving from the exploration to the exploitation phase.

Proximity, industrial lifecycle and regional lock-in

As explained, the different forms of proximity likely influence the decisions of agents with whom to connect. As individuals and organizations prefer to establish relationships with similar type of individuals or organizations, network clustering will result as similar actors group together. When linking the proximity concept to the geography of innovation networks, major research challenges remain to be taken up. These have not yet (or hardly) been explored in the network literature, but are essential for the development of an evolutionary approach to the geography of innovation networks.

The main challenge is the study of the dynamics of network formation: how do innovation networks of firms evolve in time and space, and what forms of proximity are important at what stage of the evolution of the network. The focus of attention is on the dynamics in the number of nodes and relations, and how the different forms of proximity impact on these network dynamics. It concerns both the study of: (1) the creation of relations by new firms entering the industry and by incumbent firms linking up with other nodes; and (2) the break-up of existing relations due to the exit of firms or because incumbent firms dissolve their relations with other nodes. Doing so, it covers the process of creative destruction proposed by Schumpeter, and applies that to the evolution of networks. Such an approach also accounts for the evolutionary concept of selection that basically takes place at two levels: (1) the impact of competition on firms leading to firm dynamics (i.e. the entry and exit of nodes); (2) the choice of linking or breaking with network partners (i.e. the formation and dissolution of ties) based on proximity. This means that firm dynamics are a basic input to understand the spatial formation of a network. As Klepper (2007) and others set out, spinoff dynamics is a crucial determinant of the location of industries, often leading to spatial clustering. In that respect, the emerging innovation network is most likely to cluster spatially as well, if not only because social relationships are established through the spinoff process between the parent organization and its offspring (i.e. the new spinoff companies).

Taking the industry lifecycle model as a point of departure, one can start to theorise about the network dynamics that follow. Studies have shown that after the creation of a new industry the number of firms first grows rapidly, then falls rapidly again (called a shake-out), and eventually stabilises into an oligopolistic market structure dominated by a few persistent industry leaders (Klepper 1997; Klepper and Simons 1997). Furthermore, the spatial concentration of the industry tends to increase over time as successful parents create more, and more successful, spinoffs, which locate near their parents. After the shake-out, the firms that typically survive are indeed a few early entrants and their spinoffs. Apart from the famous case of spinoffs in Silicon Valley, examples can be drawn from the U.S. and U.K. car industries (Boschma and Wenting 2007; Klepper 2007) as well as from the U.S. tire industry (Buenstorf and Klepper 2005).

From the industry life-cycle pattern, we can derive propositions about the patterns of network evolution that are most likely to emerge (see e.g. Menzel and Fornahl, 2007; Ter Wal and Boschma, 2009). First, as the knowledge base of an industry is progressively codified, the geographical distance of network relations is expected to increase over time (Menzel 2008). This has indeed been observed in German inventor networks in the biotechnology sector (Ter Wal 2009). Second, one can expect the probability to survive a shake-out to be dependent on the degree of a firm in the inter-firm network. This means that the average degree of firms increases over time. Third, given the second proposition, the falling number of firms implies that the density over relations increases over time. Fourth, as spinoffs typically have a high degree of proximity with their parent firms in the cognitive, social and geographical dimensions, network relations between spinoffs and parents firms are much more likely than any other network relation type. The resulting geography of networks is, on the one hand, characterised by an increasing number of local links between spinoffs and parent firms in the same cluster. At the same time, one expects an increasing number of global links due to the increasing codification of knowledge. Thus, even though globalisation of networks is expected to occur, the local density of network links is also expected to increase over time.

The industry lifecycle perspective can thus explain that the high density of network relations within clusters may become excessive as time passes by. As the number of firms falls over time, the remaining firms are typically embedded in strong social networks and interlocking corporate boards, which tend to resist structural change in the face of a crisis. Such resistance can be reinforced by increasing organisational proximity between firms by mutual financial participation between cluster firms as well as by higher levels of cognitive proximity between cluster firms, resulting from the long-lasting interactions in the past.

According to Grabher (1993) and Hassink (2005), such structures typically explain the inabilities of old industrial regions to successfully renew themselves. The solution to such regional lock-in phenomenon clearly lies in trying to re-organise network relations such that interactions can take place between actors that are less proximate in geographical and non-geographical dimensions. This could be accomplished by the formation of new ties that bridge unconnected networks (Burt, 2004; Gluckler, 2007). These ideas call for further refinements and thorough empirical testing (Ter Wal and Boschma, 2009).

5. Conclusion

We have made an attempt to sketch an evolutionary view on the geography of innovation networks by linking the literatures on proximity and network dynamics. To begin with, we argued that variety is a key feature of any economy, and knowledge accumulation at the firm level is its prime mover. In such an evolutionary framework of heterogeneous actors, the replication of knowledge between firms is considered troublesome unless there is some degree of proximity between actors on some dimensions: proximity is required on some (but not necessarily all) dimensions to make firms connected, and to enable interactive learning and innovation. Doing so, we have put the proximity concept into the heart of the theoretical and analytical framework of evolutionary economic geography.

Such a basic framework also enabled us to connect the proximity concept to the geography of networks. We made a distinction between five forms of proximity. Each relationship between two heterogeneous actors can be classified as being more or less proximate in all five dimensions. The dimensions, analytically defined, are orthogonal even though many dimensions may often turn out to be correlated. A proximity framework suggest that actors that are proximate in some (if not all) dimensions are more likely to connect. This approach has led to new insights in the cluster literature, for instance. Giuliani (2007) has shown that knowledge networks between firms in a cluster are not pervasive (as suggested by the cluster literature) but tend to be rather selective, because these depend on the levels of cognitive proximity between cluster firms.

While a high degree of proximity is considered a prerequisite to make actor connected, we expect the effects of network relations on innovation to be rather ambiguous. Proximity between actors does not necessarily translate into higher innovative performance, because excess of proximity may be harmful for interactive learning. We referred to this as the proximity paradox. One should therefore make a distinction between the drivers of network formation on the one hand (in which the forms of proximity positively affect the establishment of networks), and the effects of a network on innovative performance on the other hand (in which it is uncertain what the effects of proximity on network performance are). Inspired by others, we expect that, for each dimension, an optimal level of distance exists, at which interactive learning and innovation is maximised.

We also introduced some propositions about network evolution and the changing role of proximity during the industry lifecycle. This has led us to conclude that the density of network relations in geographical clusters is likely to increase over time, despite the fact that codification of knowledge facilitates long-distance networking. A high local density of network relations may well lie at the root of the problems faced by industrial areas as a too strong proximity prevents the renewal of a region’s industrial base.

We would like to finish with three research challenges that need to be taken up to build a true evolutionary perspective on the spatial evolution of innovation networks.

Firstly, a dynamic network approach should assess the relative importance of the different forms of proximity as driving forces of network formation in space. This would not only shed light on the question whether the different proximities are substitutes or complementarities, but also on the question in which stage of the network formation some dimensions play a more prominent role. For example, if geographical proximity affects network formation, is this influence persistent over time? This concerns both the study of: (1) the creation of relations by new firms and by incumbent firms linking up with other nodes; and (2) the break-up of existing relations due to the exit of firms or because incumbent firms dissolve their relations with other nodes. Doing so, the study of network formation is not only about who connects with whom and why (being dependent on proximity), but it should also be grounded in firm dynamics (which concerns the formation and dissolution of nodes).

Secondly, a dynamic network approach should make explicit how the evolution of a network structure may be seen as a path dependence process, and how that may be tested. When the current structure of a network is affecting its future structure, network evolution becomes an endogenous process: the creation of a new tie is not only influenced by the structure of the network but it also causes changes in the network (Kilduff and Tsai, 2003; Gluckler, 2007). Path dependence in network evolution is shown in the persistence of existing ties and the path-dependent formation of new ties. In the latter case, new ties replicate or reinforce the existing structure of the network (Gulati, 1999). The different proximities (besides preferential attachment) may induce path dependence in network evolution, and may cause retention in the network. These 'retention mechanisms' (Gluckler, 2007) may take place at the local level because geographical proximity plays a role, both directly and indirectly (through its effect on the other proximities). If geographical proximity matters a lot in this respect, another crucial research question holds under what conditions local network retention leads to regional lock-in, and how that may be broken apart.

Thirdly, a dynamic network approach should also account for that fact that the evolution of network structures may, in turn, affect the degree of the different forms of proximity. The study on the dynamics of proximities during network formation is an (yet) unexplored but promising field of research: it would account for the effect of networks on the attributes of nodes in the network and thus their degree of proximity in their different dimensions over time, and how that might feedback on the structure of the network (Ter Wal and Boschma, 2009). Moreover, a change in one proximity dimension can also have consequences for the other dimensions of proximity (Menzel, 2008).

In sum, we proposed an evolutionary perspective on the spatial evolution of network formation that is firmly grounded in a proximity framework. There are still many problems to be tackled before a dynamic proximity framework can be fruitfully applied to the spatial formation of networks. Having said that, we firmly believe it opens up a whole new research agenda that will contribute to a better understanding of the spatial evolution of innovation networks. In that respect, it may be a considered a crucial part of the further development of an evolutionary approach in economic geography (Boschma and Frenken, 2006).

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