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Technological relatedness and regional branching

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Abstract

The relatedness between the technologies used among firms in a region is thought to affect the nature and scope of knowledge spillovers. In this paper, we set out how the concepts of technological relatedness and related variety have enriched recent literature in economic geography. First, applying the notion of related variety has led to new insights in the externalities literature. There is increasing evidence that regions with different but technologically related activities (related variety) benefit more from spillovers. Second, the technological relatedness concept has provided additional insights to the question whether extra-regional linkages matter for regional growth: it is not inflows of extra-regional knowledge *per se*, but inflows of knowledge that are related to the existing knowledge base of regions that might be crucial. Third, the concept of relatedness has found its way in network analysis. There is evidence that collaborative research projects tend to create more new knowledge when they consist of agents that bring in related competences. Linking network dynamics to the industry life-cycle approach, one expects that cognitive proximity levels between cluster firms will increase over time, with detrimental effects on their performance levels. Fourth, the cluster literature often regards labor mobility as a key mechanism through which knowledge diffuses, but no attention has been paid to relatedness until recently. And fifth, studies demonstrate that countries and regions tend to expand into sectors that are closely related to their existing activities. To the extent that new industries emerge from related industries, the sectoral composition of a regional economy affects the diversification opportunities of regions in the long run. This process of sectoral branching occurs primarily at the regional level, because it becomes manifest through a number of knowledge transfer mechanisms (i.e. spinoff activity, firm diversification, labor mobility and networking) that tend to be geographically bounded.

1. Introduction

Technological relatedness between economic activities attracts increasing attention in economic geography. The relatedness between the technologies used among firms in a region is thought to affect the nature and scope of knowledge spillovers. First, the extent to which the variety of technologies present in a region is related is expected to affect the scope for knowledge spillovers, as firms in different but related activities can profit more from mutual spillovers than firms in unrelated activities do. Second, in the context of structural change in the regional economy in the long run, technological relatedness may well lay at the root of new industries. To the extent that new industries emerge from existing and related industries, the sectoral composition of a regional economy at one moment in time provides and constrains, but by no means determines diversification opportunities of regions in the future. This implies that the sectoral evolution of regional economies can be predicted, albeit imperfectly, from data on the technological relatedness underlying structural change.

There is no doubt that the current economic crisis has put regional diversification high on the political agenda, because specialised regions like Detroit are especially hard hit. Nevertheless, we still have little understanding of how regional diversification or regional branching exactly works, and through which mechanisms it is most likely to operate. In this chapter, we will go into the role of technological relatedness in regional development by adopting an evolutionary economic geography perspective (Boschma and Frenken 2006; Frenken and Boschma 2007). We also present some recent empirical work on the various processes through which technological relatedness in a region affect regional development, and specifically discuss how networks are both shaping and are being shaped by technological relatedness.

The chapter is organised as follows. In Section 2, we briefly introduce the notion of technological relatedness between sectors, and make the point that the concept is anything but new in the field of evolutionary economics. Schumpeter's notion of innovation, being a recombinant of existing pieces of knowledge, fits into that line of argument, but also the literature on technology systems and general purpose technologies. In Section 3, we discuss and extend the notion of related variety. In Section 4, we move to the question of how a regional economy evolves in the long-run by regional diversification. At such time-scales, related variety in a region undergoes important changes itself, and becomes a dependent variable. We introduce an evolutionary framework in which new industries emerge out of recombinations of existing industries and discuss some of the recent empirical studies providing systematic evidence for this process. In section 5, we will go into the interplay between technological relatedness and networks discussing both theoretical and empirical literature. Section 6 will draw the main conclusions and present a future research agenda.

2. Technological relatedness and economic development

The evolutionary theory of the firm argues that knowledge accumulates at the firm level through learning-by-doing. The cumulative nature of knowledge development is embodied in individuals (skills) and in firms (routines), which develop cognitive capabilities over time (Nelson and Winter, 1982; Dosi et al., 1988). Due to its tacit and cumulative nature, knowledge is actor-specific and difficult, if not impossible, to imitate by others. Therefore, variety in an economy is the rule, and knowledge accumulation at the level of individuals and firms is its prime mover. Moreover, firm growth is viewed as a progressive process of related diversification (Penrose, 1959). As the turnover of a single product is ultimately bounded by the minimum efficient scale and consumer demand, further growth requires a firm to diversify in other products. In this context, firms can be characterized by *firm routines* that apply to all products in the firm, and *product-specific routines* that are used in the production of a particular product. Yet, the product-specific routines are generally related, because firms typically diversify into products that are technologically related to its current products.

This is not to deny that knowledge will spill over now and then between firms. On the contrary, but when it does, proximity on various dimensions is required to enable effective knowledge transfer between firms (Boschma, 2005). That is, cognitive, social and geographical distances need to be overcome to connect firms, and to enable interactive learning. The cognitive dimension of proximity has attracted most attention in evolutionary economics. Due to the tacit nature of knowledge, Cohen and Levinthal (1990) have argued that firms can understand, absorb and implement external knowledge when it is close to their own knowledge base. In other words, effective knowledge transfer between firms requires absorptive capacity and cognitive proximity, to enable communication (Nooteboom, 2000).

Thus, knowledge creation and innovation is driven by interaction and feedback between individuals and firms, but only when they are related in terms of shared competences. In the 1980s, this idea of technological relatedness was applied to the sectoral level. Notions like technology systems (e.g. Rosenberg and Frischtak, 1983; Carlsson and Stankiewicz, 1991) were developed to account for technological interdependencies between industries. Key sectors were identified that heralded new technological paradigms, and which provided the main sources of knowledge for new technological trajectories (Dosi, 1982; Freeman and Perez, 1988). Since such key sectors are characterized by high pervasiveness and inter-industry cross-fertilization among emerging technologies, they bring about major economic changes, and boost long-term economic development (Breshnahan and Trajtenberg 1995).

There are several mechanisms through which industries may be technically related (Boschma, 1999). The first mechanism causing technology feedback across sectors concerns producer-user relationships. New key inputs in components or energy sources may open up new technical opportunities, which bring about major innovations in user industries. In the late nineteenth century, for example, the invention of the electrical motor enabled the mechanization in a wide range of small sectors, such as printing. The second mechanism of technology feedback is caused by production-system interdependency (Landes, 1969). Major innovations may give rise to imbalances in an interdependent production system, inducing a search process for innovations in other (less efficient) parts of the system (Dahmen, 1991). For example, the invention of the new spinning machine in the late eighteenth century resulted in a productivity bottleneck in the production chain of cotton, which induced breakthroughs in other stages of production, like carding, weaving, bleaching and printing. The third mechanism is based on technological complementarity. This concerns major innovations that have to await complementary technological advances in other industries. In the late nineteenth century, for example, electric lighting required breakthroughs in the generation of electricity in power stations, electric power transmission, and the measurement of electricity consumption (Rosenberg, 1982). The fourth mechanism concerns technical interdependencies between industries because they originate from a common technology. For example, the invention of synthetic dyestuffs sparked off the emergence of many chemical sectors in the nineteenth century, like synthetic colours, pharmaceuticals, explosives, photography, plastics and synthetic fibres.

This rather descriptive literature on technology systems in the 1980s has been followed in the 1990s by more rigorous attempts to measure the degree of technological relatedness between sectors in a quantitative manner. Based on data of multi-industry firms, Teece et al. (1994) counted the number of times a combination of two industries was found at the firm level (see also Breschi et al. 2003). Farjoun (1994) developed an indicator of relatedness taking the degree of similarity in human capital in different sectors, using occupational data (see also Bryce and Winter, 2006). Fan and Lang (2000) measured sectoral relatedness by means of input and output profiles of a sector. The relatedness measure of Hausmann and Klinger (2007) calculated the distance between pairs of products based on the probability that countries in the world export both products. Instead of determining this at the country level, Neffke and Svensson Henning (2008) calculated technological relatedness between sectors on the basis of product combinations that occur more frequently at the plant level.

3. Related variety and regional growth

Having reviewed the literature on technological relatedness in the context of economic development, we now turn to economic geography more specifically. Here, regional development is the central object of study and, logically, the role of geographical proximity in the exploitation of related technologies. Since empirical studies demonstrate that knowledge spillovers are often geographically bounded (Audretsch and Feldman 1996), it is very relevant to investigate more specifically the importance of technological relatedness for knowledge spillover effects on urban and regional growth. Technological relatedness is expected to affect, first and foremost, the extent to which knowledge spillovers occur within a region.

Since the seminal paper of Glaeser et al. (1992), the agglomeration economies literature investigates whether a specific composition of sectors in a region enhances knowledge diffusion and regional growth. This literature examines whether firms learn and benefit primarily from other local firms in the same industry, or from local firms that are active in other industries (Feldman and Audretsch 1999). As Marshall (1920) once argued, agglomeration externalities based on regional specialization may arise from thick, specialized labour markets, local access to specialized suppliers and markets, and the presence of local knowledge spillovers. Others followed the work of Jacobs (1969), who stressed the economic blessings of diversified cities, which would trigger new ideas and induce knowledge spillovers. Jacobs was among the first to acknowledge that a deep division of labour in a city could contribute to urban growth, not so much because of efficiency reasons, as Adam Smith once argued, but because it gives rise to opportunities for innovation. This brings Jacobs' work close to the ideas of Schumpeter and Penrose on innovation, who both stressed the importance of new activities branching out from (technologically) related existing activities (Frenken and Boschma 2007). We take up the issue of branching in the next section, where we apply it to the regional level.

The Jacobs' externalities literature did not, however, make an attempt to account for the effect of relatedness between sectors on urban growth in the spirit of Jacobs. All they were interested in was whether diversified cities generate more growth. However, one can question whether knowledge spillovers will take place between sectors as long as they are neighbours. Nooteboom (2000) claimed that knowledge is more likely to spill over between sectors when their cognitive distance is not too large: some degree of cognitive proximity is required to ensure effective communication and interactive learning between sectors. On the other hand, too much cognitive proximity might lead to cognitive lock-in, because no much learning will take place when agents have exactly the same competences (Nooteboom, 2000). In other words, related variety in a region is required to enable effective knowledge transfers between sectors (Frenken et al., 2007), not regional diversity (which might involve too large cognitive distance) nor regional specialization *per se* (which involves too much cognitive proximity).

What is more, the knowledge spillover effect based on related variety must be distinguished from another form of variety, that is, unrelated variety, in order to assess the effect of Jacobs' externalities (Frenken et al., 2007). Unrelated variety concerns sectors that have no substantial economic linkages. A broad range of unrelated sectors in a region may be highly beneficial for regional growth, because unrelated variety spreads risks. When a sector-specific shock occurs, it is unlikely to harm other local industries when these are unrelated, because no substantial input-output linkages exist. So, unrelated variety absorbs sector-specific shocks, and stabilizes regional economies on the longer term (Essletzbichler, 2007).

Frenken et al. (2007) have addressed the differential effects of related and unrelated variety in an empirical study on regional growth in the Netherlands. Sectors at the 5-digit level were

defined as related variety when they shared the same 2-digit category in the Standard Industrial Classification, while sectors were identified as unrelated variety when they belonged to different sector headings at the 2-digit level. As expected, regions with a high degree of related variety showed the highest employment growth rates in the period 1996-2002. These results tend to suggest the importance of knowledge spillovers across related sectors at the regional level. Such an effect has also been found in other studies on regional growth (Essletzbichler 2007; Bishop and Gripaos 2009; Boschma and Iammarino 2009).

The notion of related variety provides us with a new angle in the literature on agglomeration externalities that, until recently, was focussed on the economic effects of Jacobs' and MAR externalities in cities, with no conclusive outcomes so far. The next step to take is to account for the fact that new and related variety may also be brought into the region through inter-sectoral linkages with other regions. Boschma and Iammarino (2009) made an attempt to estimate the effects of inter-sectoral learning across regions on regional growth in Italy by means of regional import portfolio's. Their analysis suggests that the inflow of a variety of knowledge *per se* did not affect economic growth of regions in the period 1995-2003: it is not sufficient to attract large flows of extra-regional knowledge. The same was true when the extra-regional knowledge was similar to the knowledge base of the region: there is not much to be learnt from external knowledge the region is already familiar with. However, the more related the knowledge base of the region and its import profile was, the more it contributed to regional employment growth. This might indicate that a region benefits especially from extra-regional knowledge when it originates from sectors that are related or close, but not quite similar to the sectors present in the region. In those circumstances, cognitive proximity between the knowledge base of the region and the extra-regional knowledge is not too small (avoiding the learning process of being more of the same), but also not too large (enabling the absorption of extra-regional knowledge).

Since the seminal paper of Henderson et al. (1995), the agglomeration economies literature has also claimed that new (high tech) industries need Jacobs' externalities (and thus inter-industry knowledge spillovers) to develop, while more mature industries benefit more from MAR externalities (i.e. intra-industry spillovers) in more specialized cities. The question of which types of externalities are crucial for which type of industries (young or old) is indeed a crucial one (Neffke et al. 2009), but should be complemented by the question whether new (and old) industries need the local presence of related industries. Following the idea of related variety or relatedness, we would expect that a local diversity of sectors *per se* is less likely to lead to successful new combinations, because sectors will learn more from each other when they are technologically related (i.e. having some but not too much cognitive proximity). This might be especially crucial for the process of regional diversification, to which we turn now.

4. Regional diversification as a branching process

As discussed above, related variety is expected to affect the extent to which knowledge spillovers occur within regions. We argued that this sheds a new light on the variety versus specialization debate, as it follows that related variety rather than variety *per se* or specialization *per se* matters most for knowledge spillovers and regional growth. A research question that follows from this is how related variety itself can be explained as an outcome of an historical process of regional development. Note that different time scale are involved: in the short run, related variety is a very stable property as the sectoral composition of a regional economy changes only slowly over time. This means that in empirical studies that address

regional economic growth (e.g., in terms of domestic product, employment, or labour productivity), which typically deal with relatively short periods of time of one or two decades, related variety can be viewed as a given structure viz. an independent variable. Yet, on longer time-scales, related variety itself is subject to change and becomes as dependent variable in its own right. One can ask the question to what extent the technological relatedness between sectors in the economy as a whole can help us to understand the development opportunities of each single region through diversification into new and related industries. Put differently, can we understand the emergence of a new industry in a region from the level of technological relatedness between the new industry and the existing industries in a region?

This is a fundamental question, because it would shed light on how the Schumpeterian process of creative destruction unfolds over time, and how the industrial history of regions might affect the way regions create new variety (like new sectors), and how they transform and restructure their economies over time (Martin and Sunley 2006). When new variety is rooted in related activities in a region, we refer to this as regional branching. This may occur in two ways: (1) a new sector may grow out of an old sector¹; (2) a new sector may be the outcome of a recombination of competences coming from different sectors. Moreover, regions will also loose variety through exit and relocation over time. In both cases, the historical trajectories of regions are shaping (but not determining) the rise and fall of variety, but are also being shaped and transformed by this process of creative destruction.

Porter (1990) pointed out that a country might benefit from the local presence of related sectors. In fact, he presented related and supporting sectors as a determinant of national competitiveness, although his definition of related industries was quite broad. Interestingly, Porter claimed that technical interdependencies between sectors might be strongest early in the life cycle of industries. He acknowledged the importance of ‘related diversification’ (p. 123) as ‘a potent source of national competitive advantage’, which he defined as diversification into new industries by established firms from related fields. Porter made the point that this type of entry, i.e. new industries growing out of related industries, often occurs in the same region. In that respect, he claimed that future industry evolution depends to a considerable degree on the industrial history of regions.

Descriptive regional case studies have provided many details how regions may reinvent themselves by diversifying from old into new economic activities (see e.g. Bathelt and Boggs, 2003; Glaeser, 2005). The post-war experience of the Emilia Romagna economy illustrates well how related variety may contribute to economic renewal and growth at the regional level. Already for many decades, Emilia Romagna is endowed with a pervasive knowledge base in engineering. After the Second World War, a wide range of new sectors emerged out of this diffuse knowledge base. Examples are key regional sectors like the packaging industry in Bologna, ceramic tiles in Sassuolo, luxury car manufacturers in the Modena area (Maserati, Ferrari, among others), robotics, agricultural machinery, among other sectors. These new sectors not only built and expanded on this extensive regional knowledge base, they also renewed and extended it, broadening the Emilia Romagna economy.

There are other examples showing that new sectors grow out of old sectors, such as the television industry branched out from the radio sector (Klepper and Simons, 2000). The

¹ This is very different from the Darwinian type of branching in biology, in which no cross-breeding occurs between old and new species after branching. By contrast, in economics, the old and new sectors will continue to exchange information through entrepreneurship and labor mobility, which is likely to increase the survival rate of entrants in the new sector during its years of formation.

relevance of technological relatedness is not only shown though in old sectors giving birth to new sectors. More importantly, recent studies, employing survival analysis, have shown that this branching process also increases the probability of survival of the new industry. Klepper (2007) demonstrated empirically that prior experience of the founder in related industries (like coach and cycle making) increased the life chances of new firms in the US automobile sector. Boschma and Wenting (2007) showed that new entrants in the British automobile industry had a higher survival rate during the first stage of the industry life cycle when the entrepreneur had a background in these related sectors, and when the firm had been founded in a region that was well endowed with these related sectors. So, when diversifying into the new automobile sector, these types of entrants could exploit related competences and skills embodied in the entrepreneur and available in their location, which improved their life chances, as compared to start-ups lacking those related competences/skills.

Thus, from an evolutionary economic geography perspective, one would expect that a set of related industries in a region is rather persistent over time because regions are more likely to expand and diversify into sectors that are closely related to their existing activities (Hidalgo et al. 2007; Neffke and Svensson Henning 2008). This means that when firms diversify (but not many will do so because of the risks involved), they will show a higher propensity to diversify into technologically related instead of unrelated industries, because of the firm-specific routines they have built over the years (e.g. reducing switching costs), and because of the opportunities the regional environment provides. This follows Penrose's branching logic of product diversification, meaning that firms will stay close to their existing capabilities when moving into new products, and transfers this logic to the regional level (regional branching).

Recently, quantitative studies have indeed shown that countries and regions are more likely to expand and diversify into sectors that are closely related to their existing activities. Doing so, they provide evidence that regional branching occurs through related industries. Hausmann and Klinger (2007) investigated how countries have diversified their economies (proxied by their export mix) in the period 1962-2000, making use of UN Commodity Trade Statistics that include trade data on more than 1,000 different products. They argue that a high absorptive capacity of countries may not be sufficient to catch up and move in new directions. Although they put it in different words, they claim this requires related variety in a country, which is a spatial externality that induces knowledge spillovers between related sectors. Their main finding is that there is a strong tendency of the export mix of countries to move from current products towards related products, rather than goods that are less related. In other words, a country's current position in the product space determines its opportunities for future diversification. Thus the process of structural change is very much conditioned by existing related activities in a territory, providing support for spatial path dependence.

Neffke and Svensson Henning (2008) have done a similar analysis in Sweden at the regional level. The degree of relatedness between sectors was determined by means of product combinations frequently found at the plant level. They found evidence that unrelated sectors are more likely to exit the region than related sectors, while sectors that are related to other sectors in the regional portfolio are more likely to enter the region, as compared to unrelated sectors. So, regions might change their industrial profile over time, but they tend to do so in a slow manner (being a long-term process), and when they diversify, this is strongly rooted in their existing industrial profile. Consequently, industrial profiles of regions may have some predictive power as far as structural change in regions is concerned (Neffke, 2009).

However, this is not to say that every country or region has the same probability to diversify successfully into related activities. Hausmann and Klinger (2007) showed that parts of their product space were very dense (meaning that many products were related), while other parts of their product space were not. Looking at the position of countries in this product space, they could show empirically that rich countries specialised in the more dense parts of the product space, have much more opportunities to sustain economic growth, as compared to poorer countries which tend to be positioned in the less dense parts. Obviously, poorer countries have less potential to diversify successfully into related activities.

These quantitative studies tend to claim there is some coherence between the set of industries at the regional level. As Neffke (2009) puts it, ‘regional portfolios of industries are not random, but rather a coherent set of related industries. This coherence is preserved over time as regions are more likely to expand into industries that are closely related to their present portfolio than into industries that are very dissimilar to their main economic activities’ (p. 1). Although more research is needed, the fact that regions might be considered coherent entities to some extent may be attributed to intangible assets in regions, as reflected in their knowledge base and institutional set-up, that have cumulative and collective features, and which are difficult to imitate by firms in other regions (Maskell and Malmberg 1999). That is, once a region specializes in a particular knowledge base, this will act as an incentive, offering opportunities to local firms for further improvements in familiar fields of knowledge on the one hand, and as a selection mechanism, discouraging knowledge creation that does not fit into the regional knowledge base on the other hand (Boschma, 2004). As a result, the regional accumulation of tacit knowledge provides an intangible asset that is hard to grasp for non-local firms, because geographical distance (among other forms of distances) forms a barrier for the transfer of tacit knowledge (Gertler, 2003).

The mechanisms carrying knowledge spillovers between local firms contribute further to specific knowledge accumulation at the regional level. Empirical studies just presented show that countries and regions are more likely to diversify into related activities. The reason why routine replication through sectoral branching tends to operate at the regional level is that branching occurs through knowledge transfer mechanisms like spinoff activity, firm diversification, labor mobility and social networking, all of which tend to have a local bias. That is, most spinoffs locate near their parent firm, most new divisions are created inside existing plants, most employees change jobs within the same labor market area, and social networks through which knowledge flows tend to be often local. This means that the lineage structure between routines is spatially structured: once certain routines (*casu quo* industries) become dominant in certain regions, subsequent evolution of these routines into related industries is expected to occur primarily in the same region (Rigby and Essletzbichler, 1997; Essletzbichler and Rigby, 2005; Boschma and Wenting, 2007).

5. Networks and proximity

We now turn to the interplay between technological relatedness and networks. We will argue that the recent literature on networks can be enriched by taking into account the concept of technological relatedness. Conceptually, the relationship between relatedness and networks goes both ways. In a proximity framework, one can investigate the extent to which relatedness, or ‘cognitive proximity’, affects the probability of networking (section 5.1). We explain how cognitive proximity may be a prerequisite to connect, but it may not lead to major breakthroughs and new recombinations. For this to happen, one needs an optimal level

of cognitive proximity, which is line with the logic behind related variety. Networking in turn can affect technological relatedness between firms. Firms engaged in networking are expected to increase the cognitive proximity as a result of a learning process. This means that a dynamic perspective is needed to fully understand the relationship between technological relatedness and networks (section 5.2).

5.1 Optimal proximity and network performance

In recent literature, studies have attempted to understand the formation of networks. Reasoning within a proximity framework (or sociology's equivalent of *homophily*), a high degree of proximity between agents is considered a prerequisite to make them connect. One such proximity dimension is cognitive proximity which, in the context of our discussion of technological relatedness, can be defined as the extent to which agents' competences are technologically related. Not by chance, cognitive proximity and 'technological proximity' are often used in the same manner in contexts where proximity refers to agents.

Though more proximate agents tend to engage more often in networking, when assessing the economic effects of networks, proximity between agents in networks may not necessarily increase their innovative performance, and may possibly even harm it (Boschma, 2005; Broekel and Meder, 2008). Boschma and Frenken (2009) have referred 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, and the effects of networks on innovative performance on the other hand.

We claim that the economic success of a network relation may depend on optimal levels of proximity between agents on the various dimensions. 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. Or one might classify all relations along a continuum and 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 optimal level of cognitive proximity follows from the need to keep some cognitive distance (to stimulate new ideas through recombination) and to secure some cognitive proximity (to enable effective communication and knowledge transfer) at the same time (Cohendet and Llerena 1997; Nooteboom 2000). Moreover, a very high cognitive proximity generally implies that two firms have very similar competences, which means that when they engage in knowledge exchange in networks, they run a serious risk of weakening their competitive advantage vis-à-vis the network partner. It is also for this reason that one expects that excessive cognitive proximity may be harmful to performance. 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 performance of firms. They found evidence of an inverse U-shaped function between technological distance and successful exploration, suggesting the importance of some optimal level of cognitive proximity between alliance partners. Broekel and Boschma (2009) found a similar result when investigating the ego-networks of firms in the Dutch aviation industry.

Note here that such optimal levels of proximity are likely to exist for the other forms of proximity as well (Boschma, 2005). With respect to geographical proximity, one could think of 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, as suggested by Camagni (1991) and Bathelt et al. (2004). With respect to social proximity, the optimal social distance might consist of a balance between embedded relationships within cliques and strategic ‘structural hole’ relationships among cliques (Fleming et al. 2007). Uzzi (1996) found evidence of optimal social proximity, meaning a mixture of low proximity (arm’s length ties) and high proximity (embedded ties) was best for firms. For institutional proximity, an optimal level consists of operating simultaneously in various institutional regimes, such as multinationals operating in different countries, or high-tech labs cooperating with industry, government and academia. An optimal level of organizational proximity is accomplished by loosely coupled networks with weak ties between autonomous agents, which combine advantages of organizational flexibility and coordination (Grabher and Stark 1997).

5.2 Proximity dynamics in networks

A challenge is to explain the dynamic interplay between technological relatedness and network formation. This can be done by incorporating both concepts into the industry life-cycle approach. Such a study of network dynamics includes: (1) the creation of relations by new firms entering the industry and by incumbent firms; and (2) the break-up of existing relations due to the exit of firms, or because incumbent firms dissolve their relations with existing nodes. Doing so, both dimensions of the process of creative destruction are included and applied to the evolution of networks. Such an approach accounts for selection forces that operate at the level of nodes (entry and exits of firms due to competition) and the level of ties (formation and dissolution of ties due to changing proximities).

Taking the industry life-cycle model as a point of departure, one can start to theorize about the network dynamics. Studies have shown that after the creation of a new industry, the number of firms first grows rapidly, then falls rapidly again, and eventually stabilizes into an oligopolistic market structure dominated by a few 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 well-known case of spinoffs in Silicon Valley, examples can be drawn from the evolution of the car industry in the US and the UK (Boschma and Wenting 2007; Klepper 2007), as well as from the U.S. tire industry (Buenstorf and Klepper 2005).

From this industry life-cycle pattern, we can derive a number of propositions about the patterns of network evolution that are most likely to emerge (see e.g. Menzel and Fornahl 2007; Boschma and Frenken 2009; Ter Wal and Boschma 2009). As explained in Section 4, new industries generally emerge from a recombination of technologies. Therefore, we first expect new entrants with strong links to technologically related industries to have a higher survival rate, at least during the years of formation. These links may be embodied in experienced entrepreneurs (meaning founders that gained experience in related industries), experienced diversifiers (incumbents that diversified from related activities), experienced labour (firms recruiting skilled labour from related activities) and network ties (with partners that have related competences). Second, with the formation of new industries and progressive technological development within the industry, the knowledge base of firms within the industry is progressively codified. This means that with cognitive proximity between firms rising as firms become technologically more related, the geographical distance of network relations is expected to increase over time (Menzel 2008). This has been observed in German

inventor networks in the biotechnology sector (Ter Wal 2009). Third, one can expect the probability to survive a shake-out to be dependent on the firm's degree in the inter-firm network. This means that the average degree of firms will increase over time. At the same time, the falling number of firms implies that the density over relations will increase over time. Fourth, as spinoffs typically have a high degree of cognitive proximity with their parent firms, network relations between spinoffs and parents are more likely to occur than any other relation type. Thus, the resulting geography of networks is likely to be 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 increasing knowledge codification. Thus, even though globalisation of networks is expected to occur, the local density of network links is expected to increase as well over time.

The industry life-cycle 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 declines 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 crisis. Such resistance can be further reinforced by increasing organisational proximity, due to mutual financial participation between cluster firms. All these processes will further increase the cognitive proximity between cluster firms, which will result into an excess of cognitive proximity. 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 cognitive space, yet not too distant. Put differently, to foster innovation, new technologies need to be explored to examine the potential of recombinatory innovation between different technologies. Such cognitive widening is most likely to be realised through the establishment of networks outside the region (Boschma and Iammarino 2009).

5. Conclusions

Technological relatedness and related variety are powerful concepts because they affect the scope of knowledge spillovers at the regional level. First, regions with different but technologically related activities (i.e. related variety) benefit more from spillovers. Second, both qualitative and quantitative studies demonstrate that countries and regions tend to expand into sectors that are closely related to their existing activities. To the extent that new industries emerge from related industries, the sectoral composition of a regional economy affects the diversification opportunities of regions in the long run. Third, regions tend to have a rather coherent set of related industries, as regions are more likely to diversify into related activities and to shake off unrelated activities. The reason why branching occurs at the regional level is because it becomes manifest through knowledge transfer mechanisms (such as spinoff activity, firm diversification, labor mobility and networking) that tend to be geographically bounded. Fourth, relatedness in networks (as proxied by optimal level of cognitive proximity) tend to favor the (innovative) performance of partners and networks. Linking network dynamics to the industry life-cycle approach, one expects, among other things, that cognitive proximity levels between cluster firms will increase over time, with detrimental effects on their performance levels.

Our chapter has given witness of how the concepts of technological relatedness and related variety have enriched recent literature on different topics in economic geography, and we expect it will continue do so in the near future. First, applying the notion of related variety has led to new insights in the externalities literature. There is increasing awareness that it is not so much regional specialisation or diversification *per se* (Jacobs' externalities) that induce knowledge spillovers and enhance regional growth, but a regional economy that encompasses related activities with shared competences. Second, the technological relatedness concept has provided additional insights to the question whether or not extra-regional linkages (local buzz or global pipelines) matter for regional growth. Adopting a relatedness framework, empirical studies tend to show it is not inflows of extra-regional knowledge *per se* that matter for regional growth, but inflows of knowledge that are related (but not similar) to the existing knowledge base of regions that make the difference. Related flows concern new knowledge that can be understood and exploited and, thus, be transformed into regional growth. Third, the concept of relatedness has also found its way in network analysis. There is considerable empirical evidence that collaborative research projects tend to create more new knowledge when they consist of agents that bring in related competences. Fourth, the literature on labor mobility often regards labor mobility as a key mechanism through which knowledge diffuses (Almeida and Kogut 1999; Glaeser 2005; Heuermann 2009), but no attention has been paid to relatedness until recently (Boschma et al., 2009). We believe that the economic effects of neither inflows nor outflows of labor can be properly assessed if not also considering how these knowledge flows match the existing knowledge base in firms and regions. In a study on labor mobility in Sweden, Boschma, Eriksson and Lindgren (2009) found evidence that the hiring of employees with skills that were related to the existing knowledge base of the plant had a positive effect on productivity growth of plants, while the inflow of new employees with skills that were already present in the plant had a negative impact. Fifth, the concept of relatedness has recently shown its relevance in entrepreneurship studies. Longitudinal studies show that experienced entrepreneurs (those that have acquired knowledge in related industries), and not intra-industry spinoff companies, play a crucial role in the process of regional branching, connecting the old to the new in regional economies.

A research challenge though is how to measure technological relatedness and related variety. As discussed in Section 2, researchers have come up recently with more sophisticated indicators of revealed relatedness on the basis of combinations of human skills or products that occur frequently in plants or firms (Farjoun 1994; Bryce and Winter, 2006; Hausmann and Klinger 2007; Lien and Klein, 2008; Neffke and Svensson Henning 2008; see for a discussion Neffke 2009). Doing so, one gets a more accurate picture of which industries are related to one another, and one may better capture the knowledge spillover effects of related variety. Another possible advantage of these new indicators of relatedness is that predefined and static SIC codes are left behind. Since relatedness between industries may change in the long run because of technological developments, there is a need for a flexible indicator that accounts for shifts in technological relatedness and related variety over time.

A second research challenge is to investigate in detail the potential key mechanisms of knowledge transfer that operate as effective channels between the old and the new in regional economies. As explained in Section 4, there are a number of mechanisms through which regional branching is most likely to occur. There is some systematic evidence that experienced entrepreneurs and experienced diversifiers play a crucial role in the early stages of the industry life-cycle, but only a limited number of industries have been investigated till so far. However, to our knowledge, no empirical studies have yet been conducted that have assessed the importance of labor mobility and social networking for the performance of firms

in the context of an industry life-cycle approach, and whether connections with related activities have been decisive in this respect.

To conclude, we believe that the study of technological relatedness and related variety opens up new and promising directions of research in evolutionary economic geography.

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