Innovation Networks for Regional Development. Overview and Contributions

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Abstract This chapter provides a concise conceptual overview of the literature on the relationship of innovation network dynamics and regional economic development and discusses the contributions contained in this book. The overview starts with a treatise of how the knowledge-based theory of the firm argues that, for knowledge exchange and recombination, collaborative governance forms are (dynamically) more efficient than integration or market transactions. However, while exchange of tacit knowledge best takes places in geographical proximity, knowledge with an innovative potential may well be found only outside the region. As such, innovation networks engaged in knowledge creation generally evolve over time and space in conjunction with the regions involved. This chapter provides a discussion of the relationship of network dynamics and the regional innovation system and the various policy interventions possible to ameliorate innovativeness and regional competitiveness. This chapter ends with an explanation of how agent-based computer models are used to study network dynamics and regional development.

1 Introduction

Economic growth is driven by technological change (cf. Solow 1957), which is, in turn, driven by the creation of new knowledge (cf. Rosenberg 1976; Cooke and Leydesdorff 2006). Over the last decades, progressive globalization and technological dynamics has shown that economic growth requires *regional* competitiveness (cf. Porter 2003). Policy instruments to boost regional competitiveness and regional economic development may seek to enhance the regional innovation system, to alter the mix of knowledge bases in the industry (pertaining to the specialization versus diversification debate), or to increase the dynamic efficiency of innovation networks in the region.

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This book contains a selection of the research done in the INSPIRED project financed by the German science foundation DFG, grant PY 70/8-1, and the Austrian science foundation FWF, grant I 886-G11. The research goal of this project is to investigate the role of innovation networks in regional economic development, and how regional economic development can be enhanced (in)directly by using innovation networks. Given its deliberately multidisciplinary composition, the INSPIRED team from the University of Hohenheim and the AIT Austrian Institute of Technology has conducted both case studies and has studied innovation network dynamics and regional development using (empirically calibrated) agent-based computer models. In practicing and not only preaching the adage “collaborate across disciplines for innovation”, the editors of this book have asked several highly innovative peers at the Arizona State University, at the University of Naples Federico II, and at the European Academy of Technology and Innovation Assessment to contribute a chapter in which they shed their light on the matter.

2 Knowledge-Based Perspective on Collaboration

Typically, new technology is produced by combining and creating knowledge from different knowledge bases (cf. Arthur 2009). According to the knowledge-based theory of the firm, recombination of (tacit) technological knowledge is particularly efficient within one and the same vertically integrated firm (cf. Kogut and Zander 1992). However, during the inception stage of industry formation, there is substantial technological uncertainty and firms are reluctant to invest in integrating knowledge and capabilities. On the other hand, there is a market failure in exchanging knowledge: the value cannot be determined prior to knowing it, while there is no incentive to pay for knowledge once revealed. As such, the knowledge-based theory of the firm argues that, for knowledge exchange and recombination, collaborative governance forms are (dynamically) more efficient than integration or market transactions (cf. Grant and Baden-Fuller 1995). In evolutionary economic theory, collaborative innovation networks are seen as the locus of knowledge creation (Pyka 2002). As economic forces have firms specialize on core competences (cf. Wernerfelt 1984; Barney 1991; Prahalad and Hamel 1990), these firms are bound to collaborate with firms and research institutes with complementary competences and thus form (dynamic) production and innovation networks (cf. Håkansson and Snehota 1989). Indeed, strategic collaboration and innovation networks are persistent organizational phenomena in industrial innovation (e.g. Hagedoorn 2002).

Generally, innovative combinations of knowledge are those that are not too similar, nor too dissimilar (Nooteboom et al. 2007). For firms to develop radical breakthrough technology, they need access to (non-obviously) related and yet unexplored external knowledge bases, arguably present in other industries (cf. Nooteboom et al. 2007).

3 Geographical Dimension of Innovation Network Dynamics

Given that technological knowledge generally has a tacit component (Polanyi 1967), conveying and combining knowledge with a substantial tacit component is more efficient (and effective) when done face-to-face (cf. Gertler 2003). So, from a knowledge-based perspective, firms locate their innovation activities close to those of component suppliers, customers, and competitors. In addition to that, firms within one and same industry tend to agglomerate to share a pool of skilled labor, find specialized component suppliers, and reap localized scale economies (together forming the so-called Marshall-Arrow-Romer externalities). So, while firms may thus agglomerate to capture localized knowledge spillovers (Audretsch and Feldman 1996; Asheim and Coenen 2005), geographical proximity per se is not sufficient for innovation to take place as the social, institutional, and organizational ties are required to transfer technological knowledge (cf. Boschma 2005; Knoben and Oerlemans 2006; Boschma and Ter Wal 2007).

As argued above, innovation requires synthesizing a new combination of knowledge. Firms thus need to find alien technological knowledge that is a potentially innovative combination with their own core knowledge. If this knowledge is not found in the region (and in any case outside the cluster), it must necessarily come from a different region (cf. Menzel and Fornahl 2010), imported through pipelines and absorbed and used in a local buzz (Bathelt et al. 2004). Typically, industries start with new knowledge that is largely still tacit. Over time, product designs crystallize and knowledge becomes codified (Ter Wal 2014). With that, face-to-face communication and thereby co-location for exploitation and extension of that knowledge base is no longer required (cf. Ter Wal 2014; Audretsch and Feldman 1996).

Despite this rather clear pattern in the nature of knowledge over the development of an industry, there are two opposing hypotheses on the pattern in the geographical span of research collaboration (see Vermeulen et al. 2016). Firstly, there is the "outside-in" pattern (cf. Bathelt et al. 2004; Neffke et al. 2011) in which alien knowledge that ultimately sparks the radical breakthrough is brought in and absorbed from outside the region.[1] Marshallian externalities subsequently stimulate fragmentation and agglomeration of specialized firms, effectively making all collaboration geographically proximate. Secondly, there is the "inside-out" pattern (cf. Audretsch and Feldman 1996; Ter Wal 2014) in which the initial transfer and combining of knowledge leading to a breakthrough has to take place in geographical proximity, i.e. in the same region. Subsequently, codification takes place allowing diffusion to and absorption by agents in other regions. The patent analysis in Vermeulen et al. (2016) reveals that breakthrough knowledge quickly diffuses

[1]Here 'region' refers to a geographical area typically smaller than the average size of a country.

(in part due to international co-inventor partnerships), but that more applied and specific follow-up innovations take place increasingly regionally.

4 Relationship of Network and Regional Competitiveness

The (dynamic) efficiency of the networks completely or partially in the region immediately affects the regional competitiveness. After all, if networks (partially) in the region fail to keep up with global technological developments, the region will incur an economic setback. A technologically specialized region (or, rather, a cluster or industrial district) may fall behind others whenever committed to inferior technology (i.e. a lock-in) or failing to absorb, imitate, or leapfrog the technology developed elsewhere (cf. Menzel and Fornahl 2010; Saxenian 1994; Valdaliso et al. 2013; Hassink 2005; Martin and Sunley 2006). A diversified region is, in this regard, more resilient (for an extensive discussion of this concept, see Christopherson et al. 2010). However, the causality is circular. With innovation networks entirely or partially located in regions with technological clusters, and such clusters essentially competing on a progressively globalized demand market, the characteristics of these regions are of competitive significance (cf. Porter 1998, 2003).

Long-term competitiveness of regions depends on (1) access of firms in the local network to diversified knowledge, and (2) system functions supporting the innovation processes in the region. Firstly, to realize path-breaking innovations, firms in the region need access to alien (albeit technologically related) technological capabilities and knowledge. In a technologically *specialized* region, firms need non-local relationships (Rallet and Torre 1999; Bathelt et al. 2004). In a *diversified* region, the technologically "related variety" may readily be present in the region, whereby firms can continue to "branch" into new technology exploiting only local relationships (Asheim et al. 2011; Boschma 2011). Indeed, if there are more technological clusters present in the region, supraregional ties need not be required for a sustainable growth path (e.g. Menzel and Fornahl 2010). Secondly, innovation processes take place within national (Freeman 1995; Lundvall 1992; Nelson 1993; Edquist 1997) and regional innovation systems (Cooke 1992, 2001). An innovation system provides (in)direct functions for research and development activities. Facilities such as public research institutes, industry cooperatives, research service industry, and educational institutes affect transfer, absorption, imitation, exploitation, and recombination of new technological knowledge. Funding agents, intellectual property protection, market creation mechanisms, etc. stimulate research and development indirectly. The evolving population of actors in the region actively shapes the innovation systems in which they participate. Saxenian (1994) provides an extensive comparative study that outlines functions of innovation systems.

Within the INSPIRED project, researchers have conducted studies of the structure of knowledge flows and R&D collaboration within and across regional boundaries for sectors of significance for the Stuttgart and Vienna regions. Guffarth and

Barber (2016) conduct an extensive study of the global, national, and regional aerospace industry. They find that aerospace research is highly concentrated in only a few core regions, but that these regions are technologically diverse. Regions that are more peripheral however are technologically more specialized. Interestingly, the innovation system features many education facilities and research organizations, possibly characteristic for high-tech and knowledge intensive industry, notably those relying on scientific, analytical knowledge. They also find that innovation networks are highly dynamic and a great number of firms participate only once and notably for niche technologies. Buchmann and Savchenko (2016) study the automotive industry (and notably e-mobility) in the Stuttgart region. They find that Germany is a global knowledge source at the forefront of technological development as German patents are cited extensively from Japan and the U.S.A., yet that German patents rely heavily on local knowledge. Vermeulen et al. (2016) conduct a longitudinal study of patent forward citation graphs of breakthrough inventions of the German pharmaceutical firm Bayer. They find that, while there is an *in*crease in the spatial span of co-inventors (globalization of R&D collaboration) and a rapid diffusion over the world, there is a *de*crease in the distance at which follow-up inventions are done. Vermeulen and Guffarth (2016) formulate a process model of invention featuring geographical distance as a moderating variable to study two specific breakthrough inventions in the aerospace industry. They find that both design conceptions and component knowledge are created at several locations across the (industrialized) world. Certain technological knowledge (may) flow(s) through various channels to other locations for further recombination and application, possibly culminating in yet new knowledge potentially diffusing itself.

5 Policy Implications

Numerous empirical studies have focused on regional clusters, drawing on the common rationale that territorial agglomeration provides the best context for an innovation-based globalizing economy due to localized learning processes and "sticky" knowledge grounded in social interaction. Following the framework above, policymakers have, basically, three ways of stimulating regional economic development: (1) establishing innovation networks or enhancing their dynamic efficiency, (2) enhancing the regional innovation system, and (3) altering the mix of industrial knowledge present in the region.

Firstly, network-oriented policy instruments seek to unleash the potential for knowledge inter-organizational knowledge creation and to stimulate regional growth. For instance, the formation of specialized clusters has become a common policy instrument to stimulate regional growth (e.g. Cumbers and MacKinnon 2004). Both the smart specialization and construction of regional competitiveness methods determine a technological field to focus on (Boschma 2014). The smart specialization approach aims at selecting promising technology, subsequently supporting and empowering selected entrepreneurs in realizing the technological potential as well tailoring (extra)regional ties between knowledge bases (Foray et al. 2011). Given that, Marshallian agglomeration externalities drive regions to become technologically specialized (cf. Neffke et al. 2011). However, there is also a real risk of lock-in and stifling of regional economic growth (cf. Hassink 2010; Martin and Sunley 2006). To prevent a *region* to get locked in (in one of possibly several industries), it should prevent the value *network* active in that industry to get locked in. So, regional policies should facilitate the establishment of cross-regional pipelines to acquire technological knowledge.

Secondly, direct and supporting functions for research and development, transfer, absorption, imitation, exploitation, and recombination of new technological knowledge may improve the framework conditions for a dynamic and efficient regional innovation system. This is especially important for poorly performing regions, each requiring a particular mix of interventions to enhance or restore the competitiveness (Tödtling and Trippl 2005). Schaffrin and Fohr (2016) study the case of regional energy transition. They hereby study how local communities and multi-level governance contribute to technology transition processes within regional innovation systems. The underlying idea is that local actors of various sorts are most qualified in adapting solutions to their local environment. The authors find that, indeed, local innovation depends on social processes within the community and on existing, multilevel governance patterns. So, arguably, an effective transition and societal uptake are enhanced by an integrated innovation system approach.

Thirdly, the regional resilience approach seeks to stimulate innovation and prevent a decline of (value networks in) industries within its borders by maintaining a multi-industrial knowledge diversity (cf. Bristow 2010; Menzel and Fornahl 2010) and thus enable "branching" (Asheim et al. 2011; Boschma 2011).

6 Agent-Based Simulation of Regional Innovation Networks

To study regional development in conjunction with innovation networks, we need to model how the micro-level behavior of firms conducting technology search and network formation within and across the region affects macro-level dependent variables such as the level of technological advancedness, productivity, GDP, etc. (cf. Malecki and Oinas 1999). The scientific means to study the role of innovation networks in regional development such as neoclassical equation-based modeling or system dynamics are fairly limited or restrictive (cf. Vermeulen 2016). Particularly troublesome assumptions in these classical models are that one can aggregate behavior of a "representative" economic agent and disregard the network structure. In contrast, agent-based models (ABMs) are software simulations in which each agent is an instance of a class with (1) possibly unique code for sensors, heuristics, and actuators, (2) unique encapsulated data, (3) a particular (dis)position in a shared environment. In contrast to the traditional equation-based models, agent-based models (ABMs) are particularly well-suited to study innovation processes as exploratory search of interacting agents with fundamental uncertainty due to bounded rationality and limited information (Vermeulen and Pyka 2016a). For an introduction to the foundations of ABMs in social sciences in general, see Axelrod (1997, 2007), Epstein and Axtell (1996), and Gilbert (2008), in economic research, see Tesfatsion and Judd (2006) and Pyka and Fagiolo (2007), and for a discussion of technicalities in agent-system implementations, see Wooldridge and Jennings (1995).

In the INSPIRED project, researchers used ABMs to study the role of (the structure of) innovation networks in (supra) regional technological developments in several ways. A first way is to use ABMs to evaluate and compare simulation outcomes for different initial conditions or interventions. In such *inductive* studies, the model is (implicitly) assumed to be externally valid purely based on well-founded assumptions and operationalizations, or by ensuring the model is capable of reproducing particular stylized facts. An ABM can then be used to test hypotheses. Given the limited restrictions on what can be programmed, the real economic system can be modeled largely disaggregated and unabridged, as well as calibrated to empirical data (cf. Boero and Squazzoni 2005). Comprehensive ABMs can be calibrated to the real-world system using empirical data and thus used to evaluate effects of particular policy interventions (or simply forecast the future under laissez-faire). Moreover, in the INSPIRED project, several ABMs have been developed for evaluative studies. Paier et al. (2016) present an empirically calibrated model of the Austrian biotechnology innovation system to analyze the effect of different public policies on the technology profile of this industry. Their results regarding diversification versus specialization effects of policies demonstrate the value of this empirical ABM approach in the context of ex-ante impact assessment of public research policy in a regional context. Ponsiglione et al. (2016) use a comprehensive ABM of a regional innovation system called CARIS (Complex Adaptive Regional Innovation System) to engineer innovation policies that enhance regional innovativeness. Much like the SKIN model of Gilbert, Pyka and Ahrweiler (Gilbert et al. 2001), the AIR model of Dilaver, Uyarra and Bleda (Dilaver Kalkan et al. 2014), and the Korber and Paier model (Korber and Paier 2014), this CARIS model is a general template to be tailored for specific research or policy engineering questions. Dünser and Korber (2016) study the Vienna life-science sector and compare the effects of initial diversification versus specialization on the output of the sectoral innovation system in the region. By and large, they find that specialization was conducive to patent applications, while diversification induced more scientific publications but reduced the number of high-tech jobs. Vermeulen and Pyka (2016b) develop a spatial agent-based model with multiple regions to study effects of supraregional collaboration of firms in production and innovation on technological progress. At the core of this agent-based model is a simplification of the operational ‘artifact-transformation’ model (also presented and used in Vermeulen and Pyka 2014a, b) of how (1) production steps (‘transformations’) are combined to construct products (‘artifacts’) and (2) how these production steps are combined to discover new ones. They find that supraregional collaboration becomes more significant whenever new technology builds upon more diverse input technology. Yadack et al. (2016) evaluate the effect of market liberalization on the electricity price markup in Germany. They find that simulation outcomes may be structurally different from the empirical findings depending on initial conditions in terms of starting markup and spatial density, as well as capacity expansion and location heuristics.

A second way to use ABMs is to abductively formulate hypotheses on the behavior of real-world agents as cause for empirical realities (Axelrod 2007; Brenner and Werker 2007). As ABMs are used to study simulation results emerging from heuristically-defined behavioral rules (cf. Lempert 2002), one can formulate conjectures on which real-world behavior causes these empirical realities. However, given that software offers great freedom in model operationalization, parameter choices, etc. (cf. Dawid and Fagiolo 2008), establishing (external) validity is particularly challenging. To this end, comprehensive ABMs should be empirically calibrated, reproduce stylized facts, or produce empirically observed patterns (see e.g. the history-friendly modeling tradition, Malerba et al. 1999).

Finally, one can use ABMs *in practice* to provide insights in real-world phenomena, e.g. in the form of serious games, by reenactment of events, through participatory modeling, etc. Participatory modeling is a method in which real-world agents are involved in creating a collectively shared model of the real-world system. In this, already the process of formulating the ABM (so, regardless of whether the ABM is eventually used as a policy engineering tool or not) with the collective of real-world agents is seen as mean to create awareness of other agents in the system, to uncover systemic interactions, and think about alternative arrangements. Uebelherr et al. (2016), peers at Arizona State University, apply participatory modeling to a "heat relief network" of cooling centers (e.g. stores) that provides shelter to residents in case of extreme heat. The sessions of participatory modeling with managers of these cooling centers provided insight into how to align spatial and temporal availability of cooling centers. This research is a clear example of how explicit engagement with and governance of networks contribute to regional development.

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