Actors' Roles and Their Interactive Patterns in Innovation Networks of Green Chemistry, by the use of social network analysis and paten data

He, Yuqing

Supervisor
Schillo, Sandra

Thesis Proposal

Telfer School of Management
University of Ottawa

Contents

Introduction

From the 1990s, the ability to continually innovate has been emphasized as a key factor for the long-term growth of business firms, especially in highly-industrialized nations and industries (Dosi and Nelson, 2010). However, modern technologies convert increasingly complicated and tend to have more sub-branches. Confronted with the explosive growth of knowledge base in specific industries and the wide dispersion of knowledge resources, a lot of individual firms shift to develop a more specialized knowledge base and make a narrower range of products to efficiently keep their competitiveness and specialization in their own filed (Archibugi et al., 1999). In this case, individual firms, especially small and medium ones, probably do not have enough internal resources to perform their innovative activities (Giuliani, 2011).

Collaborative innovation is regarded as a feasible method to break through the obstacles mentioned above, contributing to reduce costs of accessing new knowledge and accelerate the speed of knowledge flows (Mu et al., 2008). In collaboration innovations, many individual firms get together spatially or non-spatially, linked by their shared activities and playing different roles and functions in the innovating process. To have a better understanding of collaborative innovation, it is important to identify what kinds of roles individuals are playing and investigate how individuals with different roles interact with their partners (Hacker et al., 2017).

Based on the views mentioned above, this paper will employ social network analysis to examine the distribution and the dynamics of collaboration networks as well as any changes in actors' roles in the industry of green chemistry. This proposal has four sections. The first section introduces four fields that are highly related to the research question of this paper (i.e. collaborative innovation, green chemistry, social network analysis, and role identification). The next section elaborates the logic of linking these four fields together and comes up with a series of research questions that this paper will probably answer. Then, the methodology and data used in this paper will be described in details in the third section and some potential contributions will be listed at the end.

1. Literature Review

1.1 Collaboration Networks in Innovation

1.1.1 Tacit Knowledge and Geography of Innovation

Collaborative innovation has evoked great interests of many researchers in the past few years. As a basic concept of innovation, knowledge could be categorized into two groups: tacit knowledge and codified knowledge. The differences between the two groups should be emphasized when knowledge transfer is discussed (Polanyi, 2009). Generally speaking, tacit knowledge refers to the knowledge that cannot be translated into a text, picture or video form which could be easily transferred without space or time limit (Lundvall and Foray, 1996). On the contrary, codified knowledge (also called explicit knowledge) is defined as the knowledge that could be transferred easily via a tangible or intangible medium, such as publications, electronic mails or computer conferencing (Zack, 1999). Apart from the different forms of communication, tacit knowledge is further related to personal understandings and emerging environments. For example, people with various backgrounds and experiences will explain the same knowledge in different ways, thereby tacit knowledge transferred in their hands will have distinct interpretations (Polanyi, 2009).

Based on the nature of knowledge, a conclusion could be easily drawn that people are always able to access to explicit knowledge since it is diffused with the use of written documents, largely ignoring great geographical distances or even time limits (Fallah and Ibrahim, 2004). For example, researchers could get close to the great thoughts of famous scientists who lived hundreds of years ago or who were active in academic circles of other nations. However, tacit knowledge can be favorably diffused only when personal interactions in close geographical proximity exist widely (Moodysson and Jonsson, 2007). To be more precise, clustering and face-to-face interactions are directly necessary for transferring tacit knowledge (Bathelt et al., 2004).

Proximity among different individuals and organizations in a spatial dimension is of great concern when considering the effectiveness of interactions in the process of transferring tacit knowledge.

Some empirical evidences has indicated that spatial proximity enhances the capability of accessing and exchanging information to a certain degree, thereby reducing the searching costs and uncertainty of entering into a new domain (Feldman, 1994).

Originally, the concept of spatial proximity generated from classical economic and geographical concepts associated with "the role of distance in economic localization" (Zamyatina and Pilyasov 2017, p121). Scholars of classical economic early focused on spatial proximity, exploring the impacts of geographical distance between objects on economic activities (Torre and Wallet, 2014). With the rise of interests on agglomerations in the 1990s, the concept of proximity was picked up to develop the studies of innovation clusters and regional innovation systems by a group of scholars, such as M. Porter (2000). As a famous person in proximity of innovation, Boschma (2005) defined geographical proximity as the spatial distance or physical distance among organizations and actors. According to Moodysson and Jonsson (2007), only when innovative interactions exist within a close distance at a spatial level, knowledge could be diffused in a relatively effective manner.

1.1.2 Famous Theories in Collaborative Innovation

At the level of analysis framework, early frameworks, such as national innovation systems, have been widely discussed in academia. Lundvall firstly proposed the concept of "national innovation systems" in 1985, indicating that innovative collaborations are a series of interactive activities involving business enterprises, universities and research institutes (Lundvall et al., 1988). As Lundvall (1988) indicated, there are two basic assumptions supporting national innovation systems. The first assumption is that knowledge is highly associated with learning behaviors. And the second one is that learning is an interactive behavior under a certain institutional and cultural environment. Later, Lundvall (1994) proposed two different kinds of learning behaviors in the innovating process, i.e. experience-based learning (by doing, using and interacting, DUI) and research-based learning (by science, technology, and innovation, STI), to define the forms of learning activities in national innovation systems.

Based on Lundvall's study, OECD introduced a more detailed model of national innovation systems, refining the respective roles of the main actors (including firms, research organizations, government and other public institutions) and describing the forms, quality and intensity of collaborative interactions by bringing in a variety of factors, such as the degree of personal mobility, the level of education and skills and the financial system and corporate governance (OECD, 1999). In national innovation systems, innovating activities are not only a business of institutions (no matter it is public or private) but an interactive process with national environments and resources.

Being a further extension of the national innovation system, a collaboration model called “Triple Helix of University-Industry-Government” has been proposed by Etzkowitz and Leydesdorff (2000), describing the interactive patterns among universities, industries, and government in the innovation process at large. In the Triple Helix model, universities, acting as initial researchers, provide the basic and primary knowledge that collaborations require, industries as the product creator mainly undertake the responsibility of producing commercial goods, and governments tend to regulate markets. After a series of interactions, these three sides will adopt functions and characteristics from their partners and share the knowledge and resources when necessary (Etzkowitz and Leydesdorff, 1995)

Following the theory on national innovation systems, a series of sub-systems have also infused new energy into studies on collaborative innovation, such as regional innovation systems (e.g. Cooke et al., 1997), innovation clusters (e.g. Giuliani and Bell, 2005), technological innovation systems (e.g. Carlsson and Stankiewicz, 1991), sectoral innovation systems (e.g. Breschi and Malerba, 1997) and innovation ecosystems (e.g. Jackson, 2011). Cooke (1997) introduced an updated model of “regional innovation systems” to discuss the importance of financial capacity, institutional learning and productive culture within specific regions. In the regional innovation system, scholars paid more attention to one specific region rather than one industry, focusing more on interactions across industries in the same region (Cantner et al., 2010b). Deriving from national innovation system, regional innovation system mainly consists of four elements, i.e. internal firms, institutions (e.g. universities, governments, and public organizations), knowledge infrastructures (e.g. science part or technology incubators) and supporting policies (Doloreux, 2002). As another branch of geography innovation, innovation clusters is always focusing on one specific industry or sector in a designated region, describing the internal centralization and external linkages (Cantner et al., 2010a). Taken as an example, Giuliani (2005) investigated the absorptive capacities of internal individuals and the ability to interconnect with other clusters in the wine industry of Chile, identifying different roles of wine firms by the use of social network analysis.

In studies of both innovative clusters and regional innovation system, there are some consensuses. Firstly, the mobility of human capital, especially ones with accumulated skills or know-how, is an important form of knowledge spillover, connecting internal members and transferring required knowledge (Popescu et al., 2016). Secondly, the distribution of knowledge within regions or clusters is unequal. For example, the study of Audretsch and Feldman (2004) showed that firms in the high-tech industry (e.g. computers) obviously tended to innovate together while other industries (e.g. office machinery) took on an opposite tendency. Similarly, agglomerating activities in different regions are highly related to their local background, such as their developing history or supporting policies (e.g. Saxenian, 1996). As a third point, no matter in innovative clusters or regional innovation system, the importance of three parties (e.g. public labs or agent institutions) cannot be neglected (Graf and Henning, 2009).

1.1.3 Empirical Studies on collaborative innovation

At the empirical levels, previous studies focus on two main directions: the structure (distribution) and the dynamics (evolution) of innovation collaboration networks.

Structural properties of collaboration networks have been proved to be highly associated with any success of innovation networks (Graf and Henning, 2009). In a study on Sweden, Wilhelmsson (2016) indicated that actors in areas with large populations and diversified industries are more willing to collaborate with others in innovative activities. Eisingerich (2010) suggested a network with higher strength and openness has a higher possibility to become successful even though it is easily affected by environmental uncertainty. In the study of Cantner, Meder and Ter Wal (2010a), three regions (Northern Hesse and Jena in Germany and Alpes-Maritimes in France) showed a tendency that innovation networks which have many members with a large size and distinctive knowledge bases will have faster knowledge flows and more cooperation motivations than others without these characteristics.

From the dynamic perspective, collaborative networks widely showed a trend of expanding according to the empirical evidences of increasing intensity of cooperation and greater numbers of cooperating innovators (Schröder, 2013). Collaborative networks have been proved to vary with the job mobility of scientists and the technological overlap between actors in a study on Jena of Germany (Cantner and Graf, 2006). Emons (2010b) drew a similar conclusion that the mobility of inventors and cooperation of applicants promote knowledge spillovers, thereby stimulating the local innovative activities. In addition, diversification of backgrounds of members in innovation networks is another obvious trend. For instance, the tourist industry of the U.K. faced a huge development after collaborating local players with different backgrounds (e.g. agriculture, manufacturing, and retail) (Novelli et al., 2006).

Apart from the focus on structures and developments, there is a special branch concentrating on relationships across different innovation networks/ clusters. For example, Sun (2016) investigated the development of inter-regional innovation networks in China during 1985 and 2008, pointing out a core-periphery structure of regions according to the strength of collaborating. In this regard, Graf and Krüger (2011) indicated three contributing factors determining the development of inter-regional collaborations of innovation: (1) changes in locations of large multinational firms, (2) role shifts of central actors, especially universities, and (3) attitudes transition of network actors across a large scale. Among all actors, Graf especially highlighted the functions of relationships between core universities and other actors (Graf, 2011). In addition to factors in terms of human capital, any radical breaks of relevant technologies will also largely change the collaboration patterns in the innovation world. The study of Krafft (2011) told a story of the great change in innovation networks of biotechnology-using firms during the 1970s. Due to the discovery of recombinant DNA and monoclonal antibodies, a new discipline called molecular biology was quickly established. In the following years, an increasing number of firms have been formed or shifted to develop the technologies in terms of molecular biology, which more or less leads to a restructure of collaborative networks in the biotechnology industry (Krafft et al., 2011).

1.2 Eco-innovation in chemistry

1.2.1 History and Definitions of Eco-Innovation

The importance of eco-innovation has been realized a long time ago (see Table.1). However, in the early years, people held a traditional view that any behaviors to protect the environment is always negatively associated with economic benefits. To be more exact, any efforts on environmental protection are always regarded as costly and inefficient (Porter and Van der Linde, 1995). With the development of evolutionary economic, an increasing number of people transferred their focus from reducing costs to developing, commercializing and diffusing new technologies (Rosenberg et al., 1992). By deepening the understanding of how to convert new technologies into actual wealth, evolutionary economic provides a new perspective of explaining the relationship between environmental protection and economic growth (López and Montalvo, 2015). Ecology and Economy could improve together based on this new view. Recently, some empirical evidences have supported the positive correlation between economic growth and ecology. For example, the U.S. faced rapid growth in the green-tech market in 2014, gaining 1.3 trillion dollars of revenue and achieving 12% growth compared with the year of 2013 (Marra et al., 2017). The positive attitudes towards eco-innovation have been widely taken in recent years due to the theoretical development and empirical evidences (López and Montalvo Corral, 2012)

Table.1 Top 5 Keywords of Eco-innovation in Different Periods (except "product" and "process")

Period: 1908-1979	Plants	Technology	Development	**Operation**	**Costs**
Period: 1980-1989	**Regulation**	Innovation	Technology	**Exposure**	Development
Period: 1990-1999	**Strategy**	Technology	**Management**	**Business**	Development
Period: 2000-2011	Technology	Development	**Sustainable**	**Green**	**Reduction**

Adapted from *A comprehensive review of the evolving and cumulative nature of eco-innovation in the chemical industry* (López and Montalvo, 2015)

In recent decades, the greening of innovation drew an increasing attention in relevant fields and developed many sub-branches, such as eco-innovation (e.g. Hojnik and Ruzzier, 2016), environmental innovation (e.g. Brunnermeier and Cohen, 2003) , sustainable innovation (e.g. Boons et al., 2013), green innovation (e.g. K.C. Chen and Kien Pham, 2014) and effective innovation (e.g. Clausing and Fey, 2004). According to the literature review written by Angelo (2012), the concept of environmental innovation has been used most frequently (65%) and the rarest one is green innovation (13%).

Different papers proposed definitions of the greening of innovation from different perspectives. For example, Rennings (2000, p332) gave an early definition that the greening of innovation is a process of development and application of "new ideas, behaviors, products, and process… which contribute to a reduction of environmental burdens or to ecological specified sustainability targets". In a further developed definition, Kemp and Pearson (2007, p16) described the greening of innovation as "the production application or exploitation of a good, service, production process, organizational structure, or management or business method that is novel to the firm or user and which results, throughout its life cycle, in a reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives".

In addition, the greening of industries is not only an individual task for firms themselves but also a process with regard to social, economic, institutional and political factors (Kemp, 1994). Markard (2012) defined eco-innovation as a socio-technical system of radical transition to a more sustainable model in different dimensions, containing factors of networked actors, institutions, material artifacts, and knowledge. Rennings (2000) held a similar view that eco-innovation should involve all of the dimensions including technology, organization, society, and institutions.

According to previous definitions, Cuerva (2014) put forward a model of determinants of eco-innovation, including factors of technology push (such as technological resources), market pull (such as collaborations with competitors) and regulatory push/pull (such as public subsidies). Sometimes, public pressures and supervision is also an important reason for firms to innovate ecologically (Bonini and Görner, 2011). Kemp (1994) suggested four drivers of stimulating eco/green innovation: 1) breakthroughs in knowledge, 2) demands for new technologies, 3) a foreseeable increase in costs if continuously using current trajectories, and 4) the participation of firms with various knowledge resources and benefit appeals. To summarize, drivers of eco-innovation are multifold and complex.

1.2.2 SMEs in Eco-Innovation

When it comes to stakeholders, scholars came up with a consensus that small and medium enterprises (SMEs) are the major players of eco-innovation (e.g. Klewitz et al., 2012). Strong evidence of this consensus is that over 90% of green firms are start-ups in the U.K., requiring an amount of 27 billions of dollars of venture capital during the years of 2006 to 2013 (Marra et al., 2017). For SMEs with limited resources, eco-innovation provide a potential opportunity of starting or improving their business. On one side, innovative technologies could improve energy efficiency and reduce costs, thereby reaching their goal of getting better profitability. On the other side, large firms tend to remain unchanged due to some inherent factors such as bureaucratic management. Unlike large firms, SMEs will face less resistance under the conditions of informal communications, a flexible organizational structure and an intense motivation to change the status quo (Bos-Brouwers, 2010).

However, the limitation of resources that SMEs have also causes some challenges when they attempt to do eco-innovation. The greening of industry is always fast-changing and highly fragmented, which requires a high level of searching and absorptive capabilities. Besides, the process of eco-innovation is highly associated with diversification, professionalism and complementarity of knowledge and technologies (Marra et al., 2017). However, most SMEs lack these responding capabilities. Lee (2009) pointed out that SMEs are sometimes unlikely to own enough resources, such as time, knowledge stocks, financial and human capitals, at the beginning of investing in eco-innovation. In the meanwhile, SMEs have to face other difficulties, such as regulatory push/pull effects and complicated environments in social and institutional dimensions (Rennings, 2000). Doing eco-innovation independently is a tough task for SMEs.

In this regard, it might be a good option for SMEs to collaborate with others, such as universities, governments (policymakers) or agencies (e.g. Jenkins, 2009). For instance, the government of Austria called for the establishment of a sustainable energy cluster in 1999. Governments in other countries, such as China, Sweden, Denmark, also introduced a series of preferential policies to support the growth of green-tech from 2006 to 2010 (Marra et al., 2017). With the mutual help of their partners, SMEs are probably able to assimilate external knowledge more easily and relieve external pressures coming from regulatory push (Rennings et al., 2006). As an example, one study of Alessandro (2017) opened the door of investigation on collaborative networks in eco-innovation and used social network analysis to map the pattern of aggregating behaviors and greening clusters around the world. But up to now, most of the relevant studies are mainly focusing on qualitative methods (e.g. Klewitz et al., 2012).

1.2.3 Green Chemistry

Among industries in relation to eco/green innovation, chemistry is a typical one with a long history that could go back to the end of the nineteen century (Heaton, 1994b). “Inefficient producing”, “by-products processing” and “waste utilizing” are three hot topics during a long period (Ludwig, 2017). According to López and Montalvo (2015), the transition of green chemistry has five periods: 1) stage one from 1900 to 1979, paying attention on costs and applications of material uses, 2) stage two from 1980 to 1989, focusing on controlling waste and pollution and collaborating with environmental departments in authorities, 3) stage three from 1990 to 1999, showing a trend of higher production efficiency and cost control (reduction), 4) stage four from 2000 to 2011, transferring attention to develop new technologies (eco-innovation) and 5) stage five from 2012 to 2030 (Expected), probably concentrating on ecological technologies (e.g. climate mitigation technologies and renewable chemicals) and pollution prevention. During all of the stages, two questions have been asked frequently and continually: 1) what changed the environments in the chemical industry? and 2) who are the drivers/ determinants of eco-innovation in the chemistry? (López and Montalvo, 2015).

1.3 Graph Theory and Social Network Analysis

1.3.1 Basic concepts of Social Network Analysis

Graph theory is a quantitative study of graphs composed of nodes (or vertexes) and links (or edges, arcs, ties), exploring how pairs of objects are related within a cluster and how their properties and structures could make an influence on performances at a micro level and at a macro level (Granovetter, 1983). In graph theory, nodes (or vertexes) generally represent individuals or organizations that are involved in a specific type of activity and links always correspond to relationships among nodes (Manber, 1989). Links could be directed. For instance, a relationship between a teacher and a student carries a direction of knowledge transfer, i.e. the knowledge to be taught from teachers to students. However, relationships do not always convey a direction. In some of the collaborative networks, persons have equal status and share their possessed knowledge with their partners. In this regard, it is hard to simply impart directions to such collaborative relationships. For the directed ones, links among different nodes equip with an arrow to stand for the flows between pairs of nodes.

Table.2 Fundamental Concepts of SNA

Concepts	Brief Description
Actors (or nodes)	The discrete entities within networks, including individuals, corporates, or collective social units.
Edges (or ties)	A linkage between a pair of actors, including: ⇒ Personal evaluation, e.g. liking or respect ⇒ Transfers of material resources, e.g. business transactions ⇒ Association or affiliations, e.g. social club or social events ⇒ Behavioral interactions, e.g. talking together or sending email ⇒ Physical connections, e.g. a road connecting two points ⇒ Formal relations, e.g. authority ⇒ Biological relationship, e.g. kinship
Groups/ Clusters	The collection of all actors on which ties are to be measured by theoretical, empirical or conceptual criteria that actors in the group belong together in a more or less bounded set. *A network can contain many groups of actors, but only one actor set.
Bridge	An individual whose weak ties fill a structural hole, providing the only link between two individuals or clusters.
Networks	A finite set or sets of actors and the relation or relations defined on them.

Adapted from *Social Network Analysis – methods and applications* (Wasserman and Faust, 1994)

As an analytical tool originating from graph theory, social network analysis (SNA) is introduced to investigate the valuable information conveyed on relationships among actors (some basic concepts are shown in Table.2), describing the distribution and the dynamics of overall or partial networks (or clusters) by the use of some mathematical measures, such as centrality and centralization (Chang and Shih, 2005).

1.3.2 Applications in Collaborative Innovation

According to Von Hippel (1987) and Fagerberg (1994), innovative collaborations are networked, complex and sometimes systemic so that social network analysis is a matched analytical tool in consideration of these characteristics. In social network analysis, actors within innovation networks can be regarded as nodes and collaborative relationships are visualized as links between each pair of nodes. Since each of the collaborators in reality always owe many different relationships that make them embedded deeply into networks of collaboration, social network analysis can provide a more visual and clear analysis on collaborative activities (Hung, 2017).

In addition, directions of knowledge flow in an innovative process can be investigated by using social network analysis (Breschi and Lissoni, 2009). For example, Ye (2015) employed patent citations to test the knowledge flows of three technical fields (i.e. computer & communication, drugs & medical and electrical & electronic) around the world, describing how knowledge flows in and out of different countries. On this condition, scholars have the opportunities to understand the orientations of knowledge flows and further a more straightforward understanding of innovative collaborations.

By summarizing previous papers, social network analysis is commonly used in studies of two economic fields: “clustering innovation” and “regional innovation system”. In the beginning, cluster papers focus on internal linkages, discussing behaviors of interactive learning among network members (Ter Wal and Boschma, 2009). Later, scholars’ attentions have been explored to external linkages after they are quickly aware of the potential “lock-in” risk that an excess of internal relationships and lack of external attentions might induce clusters to be inward-looking and homogeneous, thus being hard to acquire innovative knowledge when necessary (Storper and Venables, 2004). In studies using SNA to investigate innovation networks, two questions are asked frequently: a) how is the innovation network/cluster structured (e.g. Giuliani and Bell, 2005), and b) who are the cores and the peripheries in networks/clusters and why they are endowed with a position with a higher/less centrality at a micro level (e.g. Gay and Dousset, 2005) and a meso level (e.g. Boschma, 2005).

When it comes to literature on regional innovation system, three major topics are investigated: a) the distribution of key persons within and out of targeted regions (e.g. Fritsch and Kauffeld-Monz, 2010), b) the dynamic of networks over time (e.g. Schröder, 2014), and c) the influences of networking activities on their economic performances (e.g. Bell and Giuliani, 2007). A series of questions are examined, such as who are the agents connecting internal and external resources? Is preferential attachment positively or negatively associated with the development of networks? Are similarities a core contributing factor for actors to gather and collaborate? For example, Krätke (2010) used social network analysis to investigate the distribution and properties of actors within a regional network. Steiner (2010) borrowed three different methods (one of which is social network analysis) to examine structures of innovation networks at a technical, an institutional and a regional level.

In papers using social network analysis, the core question is whether networking activities could stimulate and even accelerate the transfer and diffusion of knowledge, thereby making a significant influence on economic performances. Some examples have been shown as Table.3.

Table.3 Examples of Patent-based Studies on innovation networks by using SNA

Author (Year)	Title	Research Focus
(Cantner and Graf, 2006)	The network of innovators in Jena: An application of social network analysis	Describe the <u>evolution</u> of the <u>innovator networks</u>
(Cantner and Graf, 2008)	Interaction Structures in Local Innovation Systems	Describe the evolution of the innovator network
(Graf and Henning, 2009)	Public Research in Regional Networks of Innovators: A Comparative Study of Four East German Regions	Describe the distribution of <u>key actors</u> in <u>regional innovation networks</u>
(Schiffauerova, 2009)	Knowledge flows in clusters and innovation networks: The case of Canadian biotechnology and nanotechnology	Describing the structure and evolution of innovation networks Investigate the distribution of key actors in regional innovation networks

(Emons, 2010a)	Innovation and Specialization Dynamics in the Automotive Sector: Comparative Analysis of Cooperation & Application Networks	Describe the evolution of the innovation networks
(Dolfsma and Leydesdorff, 2011)	Innovation systems as patent networks: The Netherlands, India and nanotech	Describe the distribution of technical classes in regional innovation networks
(Graf, 2011)	Gatekeepers in regional networks of innovators	Describe the distribution of key actors in regional innovation networks
(Krafft et al., 2011)	The knowledge-base evolution in biotechnology: a social network analysis	Describe the structure and evolution of technical classes in innovation networks
(Maggioni et al., 2011)	Treating Patents as Relational Data: Knowledge Transfers and Spillovers across Italian Provinces	Describing the structure and evolution of regional innovation networks
(Shih-Hung and Weng, 2012)	The network effect on technological innovation - by the analysis of affiliation network	Describe the core-and-periphery position of actors in innovator networks
(Schröder, 2013)	Dynamics in ICT cooperation networks in selected German ICT clusters	Describe the effects of innovator networks
(KC Chen and Kien Pham, 2014)	A study on knowledge flows of dye-sensitized solar cells' patent	Describe the evolution of the innovator networks
(Huallacháin and Lee, 2014)	Urban centers and networks of co-invention in American biotechnology	Describe the distribution of key actors in regional innovation networks
(Hu et al., 2015)	R&D internationalization patterns in the global pharmaceutical industry: evidence from a network analytic perspective	Describing the structure and evolution of global innovation networks
(Ye et al., 2015)	Study on the measurement of international knowledge flow based on the patent citation network	Describe the core-and-periphery position of global innovation networks
(Sun, 2016)	The structure and dynamics of intra- and inter-regional research collaborative networks: The case of China (1985-2008)	Describing the structure and evolution of regional innovation networks
(Yoon and Park, 2017)	Triple helix dynamics of South Korea's innovation system: a network analysis of inter-regional technological collaborations	Describing the structure and evolution of regional innovation networks
Summarized by this paper.		

1.4 Roles of Actors in Collaborative Innovation

1.4.1 The Importance of Actors

Innovation networks always involve more than one actor. For example, as mentioned before, the Triple Helix Model of innovation includes three sides of actors, i.e. universities, government and industry. Considering the past literature, this paper will focus not only on individual actors but also corporates and institutes.

On one hand, since effectiveness and productivity of innovation networks largely depend on the knowledge diffusion that is partially uncodified and bound to individuals (Story et al., 2011), key individuals possessing the crucial tacit knowledge should be put into a suitable position within collaborative networks, integrating other cooperators, sharing essential information and inspiring the generation of new ideas (Nerkar and Paruchuri, 2005).

On the other hand, actors tend to cooperate with others with a greater reputation and better resources (Ebbers and Wijnberg, 2010). Linking with network theory, this tendency could be explained by two principles of networking, i.e. time and preferential attachment (Goetze, 2010). "Time" means the timing that actors come into the collaborative network. When an industry is in a stage of introductory, few actors choose to enter into this field. However, as long as these pioneers survive from the start-up period, they will earn a relatively high reputation among the specific circles, attracting others to gather and collaborate (Goetze, 2010). As for the "preferential attachment" principle, Goetze (2010) indicated that innovation actors prefer to collaborate with others who have established many relationships and possessed abundant resources within and outside networks. Additionally, the heterogeneity of actors' resources will also make a far-reaching influence on innovation performances (Corsaro et al., 2012). Therefore, identifying key actors and analyzing their characteristics are crucial and significant to help understand the patterns of collaborative networks.

1.4.2 Actor's Roles

When discussing actors' performance, the roles they play within and outside networks should be emphasized. Detecting roles of actors gives us a valuable lens to investigate at a micro level, describing patterns of their daily activities of innovation (Story et al., 2011). Some previous papers in terms of collaborative innovation have already employed role theory to study actor's performances, such as inter-organizational networks (Miles and Snow, 1992) and industrial networks (Von Malmborg, 2004). Researchers of innovation fields also realized the potential advantages of using role theory to explain collaboration networks. For example, a study on science-and-technology-based SMEs used the role theory to examine how SMEs gradually grow in the process of networking with other actors with different roles (Möller et al., 2005). Based on role theory, actors can be divided into several collections according to their expected behaviors in particular situations (Anderson et al., 1998). For example, some of the roles require a higher level of technical skills or professional knowledge, while other roles depend more on human or funding resources that actors have (Humble and Jones, 1989). Also, the distribution of role collections is likely to vary in the course of developing innovation networks. Any update of technologies, knowledge or capitals will all have an influence on the role distribution of actors (Herrmann et al., 2006).

In previous papers, a series of roles have been defined and identified according to functions they play in the process of knowledge transfer. The most direct method is to assign different roles according to different periods actors work for. For example, Geisler (2007) separated the whole process of innovation into four stages (i.e. generation, transfer, implementation and absorption) and assigned three roles of actors (i.e. generators, transformers and users). Based on a literature review of the innovation process, Reinhardt (2011) introduced a typology conveying ten different roles according to their functions and activities in innovation collaborations. They are controllers, helpers, learners, linkers, networkers, organizers, retrievers, sharers, solvers and trackers. In a further study, Hacker (2017) suggested an updated typology of roles including initiators, debaters, sharers, coordinators, seekers, helpers, experts, networkers, linkers and observers. Other similar typologies have been proposed by scholars, such as Chan (2010). This kind of method provides supporting logic for many studies on role identification in innovation networks, concentrating more on the actions of individuals rather than interactive patterns between different actors (Hacker et al., 2017).

Another method of identifying actors' roles also occupied an important position in this field, mainly focusing on the functions of connecting and communicating with internal and external actors. For example, gatekeepers have been identified as a role of helping to access external knowledge, assimilate it and then diffuse within local networks (Graf, 2011). Taken as another example, relationship promotors are defined as individuals who deal with internal and external collaborations by using the trust they gained before (Fichter, 2009). Other similar roles are widely proposed, such as third parties (Mantel and Rosegger, 1987), technical brokers (Provan and Human, 1999), bridge builders (Bessant and Rush, 1995) and knowledge agent (Bertola and Teixeira, 2003). Generally speaking, this group of roles always motivate knowledge flows and technical spillovers across different teams, cluster, regions or industries. They are not only acting as a connecting role but also assimilating knowledge and motivating the diffusion and creation of new ideas internally (Hargadon and Sutton, 1997).

According to previous papers, roles could be identified from three different perspectives: 1) are they bonding or connecting others? 2) are they functioning internally or externally? 3) are they teaching or learning? (Some previous roles have been classified in Table.4) As for the first perspective, “bonding” means that actors links a lot of partners and has a relatively high reputation and influence on their own circle, while “connecting” refers to provide unique connections between pairs of actors, acting as a bridge to help others exchange knowledge and information (Huang et al., 2014). When it comes to “internally” or “externally”, collaborating activities intra and inter different regions/ networks/ clusters will be emphasized. In the end, learning and teaching, as the basic behaviors of the innovating process, will be investigated. This paper will identify actors’ roles from these three perspectives in the following sections.

Table.4 Typical Roles in Innovative Collaborations, analyzing from three dimensions

Roles	References	Dimension One		Dimension Two		Dimension Three	
		Bonding	Connecting	Internal	External	Teaching	Learning
gatekeeper	e.g. (Graf, 2011)		✔		✔		
local subcontractor	e.g. (Pucci et al., 2018)			✔			✔
global leader	e.g. (Pucci et al., 2018)				✔	✔	
generators	e.g. (Geisler, 2007)					✔	
transformers	e.g. (Geisler, 2007)		✔	✔	✔		
users	e.g. (Geisler, 2007)						✔
relationship promotor	e.g. (Fichter, 2009)		✔	✔	✔		
intermediaries	e.g. (Howells, 2006)		✔		✔		
knowledge broker	e.g. (Hargadon and Sutton, 1997)		✔		✔		

Adapted by this paper according to previous studies.

2. Research Question

2.1 Structure of the Literature Review

Summing up the above, there are some existing overlaps between each pair of fields mentioned above (see Figure.1 and Table.5)

Figure.1 Mapping of literature

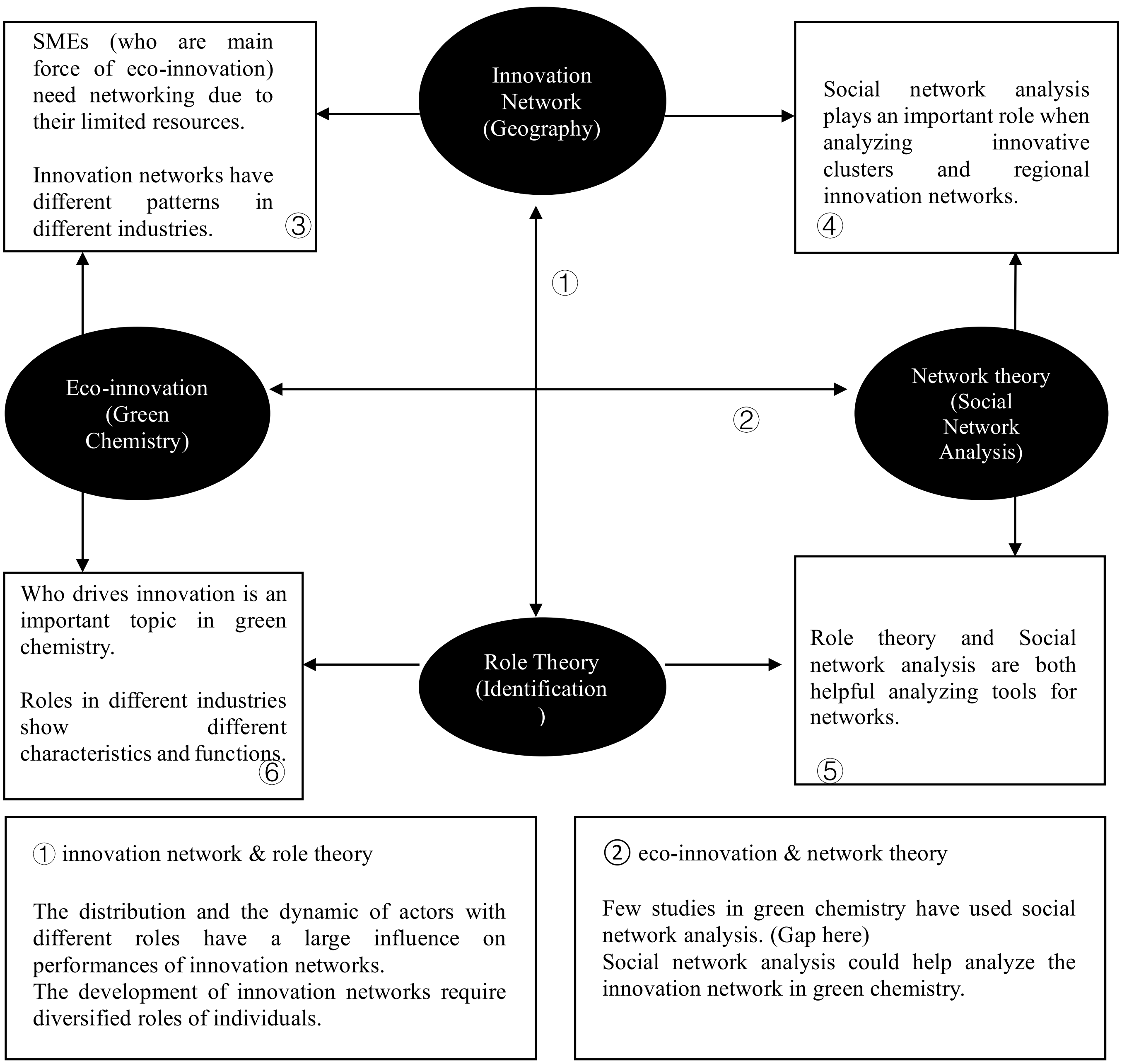


Table.5 Examples of overlap between each pair of fields

	Titles	Research Focus	Reference
①	Gatekeepers in regional networks of innovators	Examine the distribution and characteristics of gatekeepers in four innovative regions of Germany	(Graf, 2011)
②	Emerging green-tech specializations and clusters – A network analysis on technological innovation at the metropolitan level	Examine the distribution and evolution of green clusters in chemistry in San Francisco, New York and London by the use of social network analysis	(Marra et al., 2017)
③	Collaborative green innovation in emerging countries: a social capital perspective	Examine how environmental collaboration across organizational boundaries affects green innovation from the social capital perspective	(Chen and Hung, 2014)
④	The network of innovators in Jena: An application of social network analysis	Examine the evolution of the innovator network of Jena by the use of social network analysis	(Cantner and Graf, 2006)
⑤	Identifying node role in social network based on multiple indicators	Examine the distribution of roles for bonding and connecting in different kinds of social networks	(Huang et al., 2014)
⑥	Intermediaries driving eco-innovation in SMEs: a qualitative investigation	Examine the distribution of roles of intermediaries in eco-innovation.	(Klewitz et al., 2012)

2.2 Gaps and Research Questions

According to previous papers, these fields have been proved to be relative. However, there are still some gaps existing as listed below.

1) There are limited studies of green chemistry by using quantitative data or using social network analysis. The patent is a good indicator of tracing knowledge spillovers but in green chemistry, it is not used to a certain degree.
2) Most of the papers in green chemistry are focusing on drivers or determinants of eco-innovation. The question of how to collaborate and interact in green chemistry is not paid enough attention.
3) There are diverse classifications of roles in innovation networks. However, many of them share overlapped functions and characteristics even if they don't have the same title. In other words, the integration of innovative roles is necessary.

This paper will examine the distribution and evolution of actors' roles in innovation networks of green chemistry. The following research questions will be answered after analyzing:

1) How do actors interact with others in innovation networks of green chemistry?
2) How do innovation networks change over time?
3) Are there any patterns of actors' roles during the period from 1990 to 2016?
4) Are there any patterns of inter and intra regional collaborations in green chemistry?

3. Data and Methodology

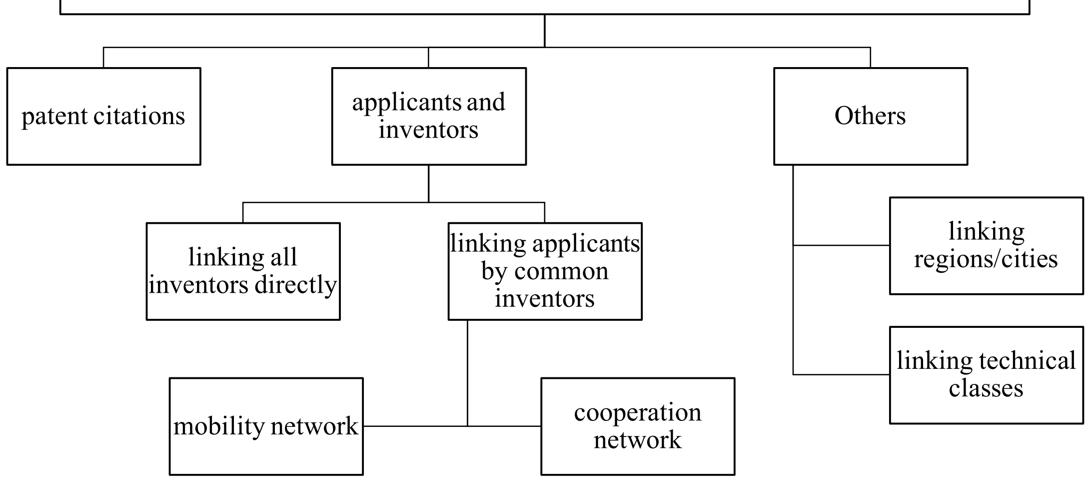
3.1 Social Network Analysis using patents

Social network analysis is an academic methodology focusing on relationships within and outside targeted networks, requiring an enormous quantity of data that are relational and easy to access (Graf, 2011). Data has two categories, i.e. primary data (such as interviews and questionnaires) and second data (such as industry reports and patents). Both of them have their own advantages and disadvantages in investigating innovation networks. Some of the previous papers in this filed adopted primary data as the cornerstones of structuring networks. For example, Bell and Giuliani (2007) used data from interviewees in three wine clusters to explore the structure of knowledge clusters, the strength/density of connecting and the intensity of external interactions. In addition, primary data could provide information such as the change in human resources of network members and communicating contents between each pair of collaborators (Bell and Giuliani, 2007). However, primary data have some inherent and inevitable shortcomings when used in social network analysis. First of all, social network analysis requires data to be abundant. That way, networks could be mapped and investigated completely (except for some special networks, e.g. ego network). But with regard to primary data, obtaining on a large scale and in a large quantity is extremely difficult, requiring a huge amount of human resource, time and funding. Apart from this, a low response rate and pre-list of target population probably lead to a potential bias when considering the overall performance of innovation activities (Ter Wal and Boschma, 2009).

When it comes to second data, a series of different sources are mentioned in previous papers, such as patent data (e.g. Cantner and Graf, 2006), co-publications (e.g.Ponds et al., 2007) and joint-venture databases (e.g. Stuart, 1998). Considering the convenience of access, this paper adopts patent data as the main data source. Patents contain a specific description of the patented products or techniques, such as fields they belong to, titles describing for what this patent is designed, and abstracts and keywords that inventors used to define their patent. But not limited as these, information about persons involved and technology classes (e.g. IPC code International patent classification) is also provided in patent documents.

Patents data have been shown as an effective indicator to explore the economic and innovative world. Taken as an example, Jaffe (1993) had used patent citations to investigate knowledge flows and innovation spillovers back in the 1990s. In addition to citations, patents also provide information on other characteristics of networked individuals. For instance, a group of scholars used the information on persons' identification (i.e. inventors and applicants) to map the collaborative behaviors (e.g. Cantner and Graf, 2006). More application methods will be introduced in the following paragraphs (see Figure.2).

Figure.2 The Use of Patents in Innovation Studies by Social Network Analysis



According to an OECD report in 2008, patents are easy to access since they are always published on official websites and downloaded without strict geographical limits. Also, patents provide a huge amount of information on innovation processes. For example, they give information about all of the members of innovative teams and core contents of innovation products, across different sectors, regions and fields. In addition, patents are relational data which offers a possible way to import social network analysis into the field of innovation studies (OECD, 2008).

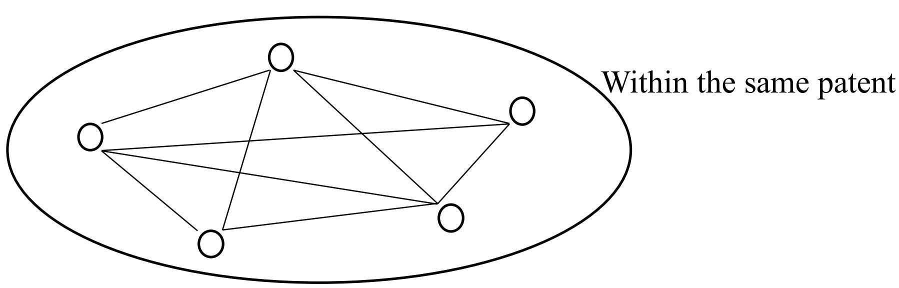
However, the use of patents have some inevitable defects. Firstly, not all of the innovative collaborations have been patented and granted officially. Influencing factors, such as application cost and secrecy, might lead to the absence of patenting (Fritsch et al., 2018). Second, patent activities show different patterns across distinct industries and areas (Arundel and Kabla, 1998). For example, Arundel and Kabla (1998) concluded that process innovations are less patented in all industries but the patenting activities of product innovations are heavily affected by the propensity of different sectors. Mairesse and Mohnen (2003) achieved a similar conclusion that patenting is more important in the manufacturing industry than in the service industry. Innovations and inventions in non-technological sectors tend to keep confidential, such as an innovation of new methods for organizational management (Fritsch et al., 2018). But weighing the advantages and disadvantages, the patent is a useful data source.

As shown in Figure.2, there are three major branches using different parts of patent data. The first one is to use citations to map the structure and flows of knowledge in patenting. There are four methods of networking citations used in previous papers: a) direct citation that links patents as long as there exists a referencing relationship, b) bibliographic coupling that establishes a linkage between two patents sharing cited patents, c) co-citation clustering that means a relationship between two patents who are cited by the same other one, and d) co-citation analysis that provides a more standard process including cited ones and citing ones (Boyack and Klavans, 2010).

When it comes to the second branch, there are two major ways of using personal information by social network analysis, sharing a common assumption that innovators and inventors within the same patent application know each other (Balconi et al., 2004). Based on the coding rules of patents data, there are two groups of involved persons documented in patents, i.e. applicants and inventors. According to previous papers, applicants might be a private company or a public research institute that hires or gathers inventors to create (e.g. Schröder, 2014) (e.g. Schröder 2013). Sometimes, applicants are also described as (potential) innovators (Graf and Henning, 2009). Inventors are always natural persons who are involved in the innovating process. They might be scientists, experts or researchers (Graf and Henning, 2009). In this context, applicants play the role of a knowledge holder, deciding whom they will collaborate with (Maggioni and Uberti, 2011).

Initially, inventors are directly linked with all of the other collaborators who work on the same patents according to the shared assumption (see Figure.3). Later, another approach was introduced on the assumption that applicants hold property rights and play the key role of exchanging knowledge (Graf, 2011). Since technological knowledge is partly regarded as tacit, only contacting at a close distance (such as face-to-face talking) could help transfer knowledge and motivate its spillovers. In other words, the holders of knowledge could largely decide the knowledge diffusion by means of choosing other specific individuals or institutes as the ones to communicate, share and collaborate in innovative activities (Maggioni and Uberti, 2011).

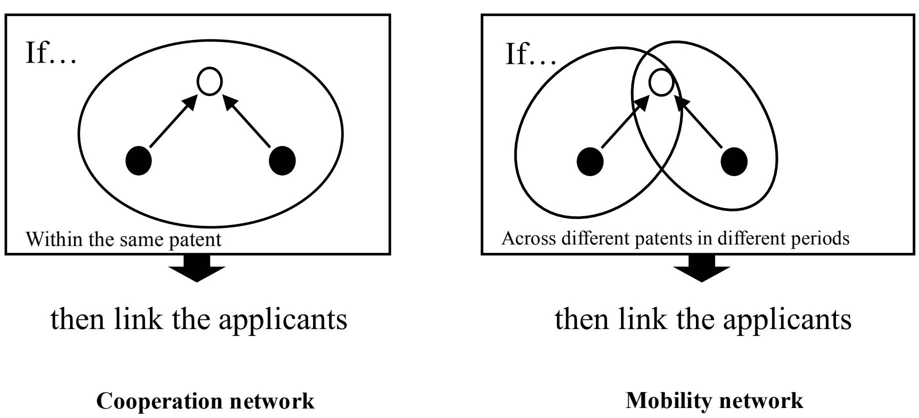
Figure.3 Linking All of Inventors Directly



Tips: Black nodes represent applicants and white nodes represent inventors. Linkages means the existence of collaborative relationships. Circle indicates all nodes within this circle are in the same patent.

In this sense, applicants are linked by common inventors (e.g. Cantner and Graf, 2006). This approach has two kinds of graphs: “cooperation networks” and “mobility networks” (see Figure.4). Cooperation networks link all co-applying innovators within the same patent as long as there is at least one common inventor. In this regard, inventors are regarded as the connection between any pair of the innovators, working for both of them. The more inventors they have, the stronger the collaborative relationships are, and the thicker the ties between each pair of nodes will present. The other graph, namely mobility network, is more in terms of personnel exchanges. If an inventor works for two distinct innovators that are not within the same patent in two periods, these two innovators will be linked since it means personal mobility between the two organizations (innovators) (Cantner and Graf, 2006). For example, if inventor A works for organization M in the period from 2006 to 2010 and jumps to organization N in the period from 2011 to 2016, then the organization M and N will be connected in the mobility network. In this approach, nodes within networks are innovators and links represent that the two innovators share at least one common inventor.

Figure.4 Linking Applicants by Common Inventors



Tips: Black nodes represent applicants and white nodes represent inventors. Linkages means the existence of collaborative relationships. Circle indicates all nodes within this circle are in the same patent.

The last application method of patents considers technical classes or regions as the nodes of networks. For instance, Breandán (2014) connected American cities by co-patenting inventors involved in the industry of biotechnology and mapped the knowledge flows among those cities.

Another example of regarding technical classes as the nodes is the investigation of Krafft (2011) that used IPC classes to partition the patents in the biotechnology sector and linked the technical classes if they are labeled under the same patent application.

3.2 Measures

In social network analysis, centrality provides a precious perspective to investigate the internal structure of networks at a nodal level (e.g. Lee and Su, 2010). There are four main centralities in social network analysis, i.e. degree centrality, betweenness centrality, closeness centrality and eigenvector centrality. Degree centrality, as the simplest one, represents the number of linkages a specific actor receives or emits, including two different types: in-degree centrality and out-degree centrality (Wasserman and Faust, 1994). The only distinction between in-degree and out-degree is the direction of ties. For example, if patent A is cited by other ten patents, we could conclude that patent A has an out-degree of 10 and other patents have 1 in-degree at least (we do not know whether they cite other patents so put an "at least" here). An actor plays a teaching role if it has a relatively higher out-degree. Otherwise, it will act as a learner. Degree centrality is the number to measure the ability of nods to which extent they can exchange knowledge with their collaborators.

The concept of betweenness is based on the frequency that a particular actor lies on the shortest link between other pairs of actors (Montresor and Marzetti, 2008). In other words, it examines the actors' ability to act as an intermediary one. In an innovation network, a node with higher betweenness centrality probably has a stronger control over the whole network since it masters a great number of channels to diffuse knowledge (Krätke, 2010).

The third type of centrality frequently used is called closeness centrality, regarded as the sum distance to all other actors within the network (Lee and Su, 2010). The closer one actor is to all others, the higher its closeness centrality is and higher influence on other actors.

And the last one is eigenvector centrality introduced on the assumption that, if an actor is linked with other important actors, it will be regarded as an important one (Huang et al., 2014). In other words, eigenvector centrality is a measure of the influence of individual actors across networks. The more actors with high eigenvector values a specific actor connect with, the higher the score it will gain.

Unlike the centrality which is focusing on the performances of individual nodes, centralization is more inclined to describe the structure of overall networks (Borgatti, 2005). It also has four main measures, i.e. degree centralization, betweenness centralization, closeness centralization and eigenvector centralization. One network corresponds with one value of each centralization measures. For example, degree centralization refers to the distribution of degree centrality of each actor across networks, indicating whether the networks are centralized or not. If the degree centralization is high, then it probably means this network has some actors with high degree centrality, thereby illustrating this network is highly centralized.

3.3 Data

Patents have been shown to be a feasible data source in the context that social network analysis is employed to investigate innovation activities.

In this paper, I will use patents data from USPTO database covering periods from 1990 to 2016 and combine them with other data sources, such as Google Maps API Geocoding. I use Google Maps API to geocode the residency of inventors and innovators, including information about cities, provinces and countries. Patents will be chosen in this paper if they have at least one person locating within Canada and I will pick up the patents with keywords that are related to green chemistry. Each patent applications might have more than one innovators (applicants) or inventors. Similarly, it is possible to see the same innovator or inventor in different applications.

The variables that we will gain from patents are shown and briefly explained as below:

appln_id Application identification means the technical unique identifier. Each application only corresponds to one application identification number. If any information is changed in this application, it will have another new id. In this paper, the application id is used to identify whether persons are collaborating within the same application.

appln_filing_year The year of the application filing date is used to separate patents of different years. For example, we could explore differences in the distribution of collaborative networks of the period between 2006 to 2010 and period between 2011 to 2016.

invt_seq_nr Sequence number of inventor indicates the status of involved persons in the same application. It has a value from 0 to n (n refers to the number of inventors that are involved in this application in total). Here, an entry with a value of "0" means an applicant (innovator). If the value is greater than "0", then the corresponding persons are regarded as inventors. Based on the methodology that will be used in the following section, an applicant (innovator) will be considered as the nodes of innovation networks and inventors as characteristics of the links between applicants. For example, if there are seven inventors cooperating in a patent that has more than one innovator, the relationship between the innovator is stronger than one that only has two inventors.

person_id Person identification is similar to that of applications. Based on the description from USPTO, persons are "the legal or physical persons that have a relation with the patent granting procedure." Only two kinds of persons are documented in our patent data, i.e. applicants and inventors.

person_address & person_ctry_code & person_cd & person_prov & person_city All of these variables are in terms of the address of persons, providing the coordinate of their location. In this context, questions, such as whether the collaboration is within or outside Canada, could be answered.

techn_sector Here, 35 technology fields are categorized into 5 technology sectors, i.e. Chemistry, Electrical Engineering, Instruments Mechanical Engineering and Other fields. The sub-fields are also retrieved as additional attributes for each application. For example, sub-fields of other fields include furniture and games, civil engineering and other consumer goods.

appln_abstract & *appln_title*   The titles and abstracts of patents provide information on what patents are particularly designed for. Here, these variables help us pick up the patents focusing on greening chemistry.

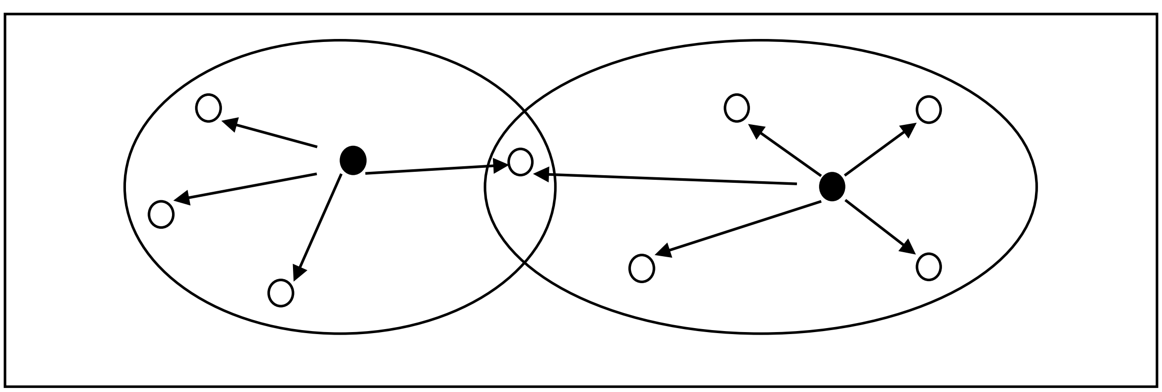
3.4 Research Design

This paper will analyze data from three different aspects, i.e. the structure of collaboration networks, the dynamic across different periods and the internality and externality within and across different regions (summarized steps see Table.6 at the end of this part).

> Part.1 Structure

Step.1 According to the identification of persons involved in innovative collaborations, two types of persons are identified (applicants and inventors). Two graphs will be provided at this step: the overall network and cooperation network. In terms of the overall network, applicants will be regarded as the start of collaborative relationships, linking inventors who are hired by corresponding applicants (see Figure.5). An additional graph will convey a clustering distribution on the basis of edge betweenness. Meanwhile, a cooperation network will help further understand the distribution and structure of the overall innovation network (see Figure.3).

Figure.5 Linking All Persons in Patenting documents



Tips: Black nodes represent applicants and white nodes represent inventors. Linkages means the existence of collaborative relationships. Circle indicates all nodes within this circle are in the same patent.

Step.2 Four measures of each node will be calculated, i.e. degree centrality, betweenness centrality, closeness centrality and eigenvector centrality. Then, according to different levels of these four measures, nodes in corresponding graphs will be assigned different colors to show a clear and straightforward distribution of nodes.

Step.3 In terms of identifying roles and their importance, this paper adopts a method called Evaluation of Importance based on Multi-Indicator (EIMI) and Role Judgement based on Multi-Indicator (RUMI) (Huang et al., 2014). Huang (2014) selected 10 typical indicators of social network analysis and analyzed the correlations of them, concluding there are significant drawbacks if only single indicator is used to identify actors' roles. After comparing the correlation coefficients of 10 indicators (i.e. degree centrality, eigenvector centrality, information centrality, density/clustering coefficient, betweenness centrality, closeness centrality, structure hole indicators including efficiency, constrain, effective size and hierarchy), Huang (2014) chose the normalized values of degree, betweenness and eigenvector centrality as the main indicators to judge the importance of actors and to identify what kind of roles they are playing.

This paper will adopt this method as a reference. The value of the importance of actors will be calculated by summing up the scores of the three indicators, evaluating actors from three different perspectives. Then RUMI has been used for role identification on the assumption that nodes will be ordinary ones if their values of degree, betweenness and eigenvector are very similar. The process is as followed: 1) compute the standardized values of three indicators and rank the actors separately by each of the indicators; 2) calculate the rank differences between individual nodes and the average differences of the overall network; 3) judge the roles of each actor according to the rules: a). if the rank based on degree centrality is top 10 percent and the differences are greater than the average, the actor could be regarded as a core, and b). if the rank based on betweenness centrality is top 10 percent and the differences are greater than the average, the actor will be considered as a bridge node. If an actor is assigned as both core and bridge, it will have a new title of "superstar", indicating this actor takes the responsibility of both bonding and connecting simultaneously.

Step.4 A basic description of overall networks will be given. For instance, how many applicants and inventors do we have? How many links have been established? How many isolates and connecting nodes and what's their percentage?

Step.5 After comparing the given graphs and analyzing basic statistics, the following questions will probably be answered:

What does clustering look like? How are the internal actors connected? What do the structure and distribution look like? Are there any special actors or special clusters? Are there any patterns of the distribution of cores and peripheries? What are their specific roles and functions? Are they bonding or connecting? Are they inward or outward?

> Part.2 Dynamics

Step.1 Two kinds of graphs will be provided here. The first one is mobility networks (see Figure.4) and the second is networks in different periods (1990-1995, 1996-2000, 2001-2005, 2006-2010, 2011-2016). Also, the clusters of different stages will be mapped.

Step.2 Four centralizations for each network will be calculated.

Step.3 After comparing the given graphs and analyzing basic statistics, the following questions will probably be answered:

How do networks change over time, in quantity, in structure and in clusters? Is there any special change (or trends, patterns) existing? Are there unchanged ones? Could we explain the preferential attachment according to what we have? Are there any important persons or groups entering and exiting?

> Part.3 Internality and Externality (inter and intra regions)

Step.1 Graphs of different regions will be made (specific steps are already shown in the first two parts). Measures of corresponding graphs will be calculated as well.

Step.2 Based on graphs and measures made in step one, the following questions will be answered:

How do collaborative networks structure and develop? Are there any special regions?

Step.3 Considering the collaborations across regions, two graphs will be made: a. the overall network assigning different colors of nodes based on regions, b. the overall network assigning different colors of links based on whether it is an internal or external linkage.

Step.4 The following questions will be answered:

What are the percentages of inter-regional collaborations? Are there any obvious trends crossing different periods? Could we find valuable patterns from these graphs and any special individuals? Are there any dominant clusters showing a significant influence on the whole network?

Table.6 Brief Summary for Research Design

Parts	Steps	Concrete operations
Part.1	Step.1	Graphs: overall & cooperation networks Additional one: clustering network
	Step.2	Calculation of four centralities
	Step.3	Identification of roles
	Step.4	Basic statistics description
	Step.5	Analysis
Part.2	Step.1	Graphs: overall (periodical) & mobility networks Additional one: clustering network
	Step.2	Calculation of four centralizations
	Step.3	Analysis
Part.3	Step.1	Graphs and measures: different regions (internal)
	Step.2	Analysis
	Step.3	Graphs and measures: different regions (external)
	Step.4	Analysis

4. Potential Contributions

This paper will explore the interlaced region among four sub-fields: the geography of innovation, social network analysis, green chemistry and role identification. According to the literature review, it is safe to say there are already some papers covering both two, or even three subfields mentioned above. In other words, these four fields have potentials to get adopted together.

However, there are very few papers using social network analysis to identify the roles of actors in innovation networks of green chemistry in the past. This paper will fill up the vacancies in this area. In addition, green chemistry has little been investigated from the perspective of innovation networks. Most scholars still put their attention on drivers of eco-innovation instead of individuals in networks. However, since most of participates are SMEs with limited resources, the importance of networking and collaborating should not be ignored in this field. Thirdly, through a long period of exploring actors' roles in innovation networks, scholars introduced a variety of roles' taxonomies, some of which have a large intersection. This paper will give a more straightforward method to identify roles, attempting to cover all functions mentioned previously.

By using social network analysis, this paper will have an analysis of the distribution and development of overall networks as well as the change in actors' roles within innovation networks in green chemistry. Changes of periods of each five years between 1990 and 2016 will be investigated and compared to in a large manner.

This paper will contribute to the theory on technological transitions in green chemistry. Furthermore, this paper will help to have a better understanding of research focusing on the roles of individuals within innovation networks. The theoretical frameworks and methods of this paper will have the potentials to form the basis for further future work.

From a methodological perspective, this paper also extends social network analysis to analyze innovation networks. In addition, the use of new measures (RUMI and EIMI) extends the current use of patent analyses by SNA. From an empirical perspective, this paper provides evidence of the transition of green chemistry in Canada, using longitudinal data. The documentation of patterns in the transition within innovation networks in these contexts will allow policy developers to recognize conducive patterns earlier and support them with appropriate policy action.

References

ANDERSON, H., HAVILA, V., ANDERSEN, P. & HALINEN, A. 1998. Position and role-conceptualizing dynamics in business networks. *Scandinavian Journal of Management,* 14**,** 167-186.

ANGELO, T. A. & CROSS, K. P. 2012. *Classroom assessment techniques*, Jossey Bass Wiley.

ARCHIBUGI, D., HOWELLS, J. & MICHIE, J. 1999. *Innovation policy in a global economy*, Cambridge University Press.

ARUNDEL, A. & KABLA, I. 1998. What percentage of innovations are patented? Empirical estimates for European firms. *Research Policy,* 27**,** 127-141.

AUDRETSCH, D. B. & FELDMAN, M. P. 2004. Knowledge spillovers and the geography of innovation. *Handbook of Regional and Urban Economics.* Elsevier.

BALCONI, M., BRESCHI, S. & LISSONI, F. 2004. Networks of inventors and the role of academia: an exploration of Italian patent data. *Research Policy,* 33**,** 127-145.

BATHELT, H., MALMBERG, A. & MASKELL, P. 2004. Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography,* 28**,** 31-56.

BELL, M. & GIULIANI, E. 2007. Catching up in the global wine industry: innovation systems, cluster knowledge networks and firm-level capabilities in Italy and Chile. *International Journal of Technology and Globalisation,* 3**,** 197-223.

BERTOLA, P. & TEIXEIRA, J. C. 2003. Design as a knowledge agent: How design as a knowledge process is embedded into organizations to foster innovation. *Design Studies,* 24**,** 181-194.

BESSANT, J. & RUSH, H. 1995. Building bridges for innovation: the role of consultants in technology transfer. *Research Policy,* 24**,** 97-114.

BONINI, S. & GÖRNER, S. 2011. McKinsey global survey results: The business of sustainability. *McKinsey & Company*.

BOONS, F., MONTALVO, C., QUIST, J. & WAGNER, M. 2013. Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production,* 45**,** 1-8.

BORGATTI, S. P. 2005. Centrality and network flow. *Social Networks,* 27**,** 55-71.

BOS-BROUWERS, H. E. J. 2010. Sustainable innovation processes within small and medium-sized enterprises.

BOSCHMA, R. A. 2005. Proximity and innovation: a critical assessment. *Regional Studies,* 39**,** 61-74.

BOYACK, K. W. & KLAVANS, R. 2010. Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately? *Journal of the American Society for Information Science and Technology,* 61**,** 2389-2404.

BRESCHI, S. & LISSONI, F. 2009. Mobility of skilled workers and co-invention networks: an anatomy of localized knowledge flows. *Journal of Economic Geography,* 9**,** 439-468.

BRESCHI, S. & MALERBA, F. 1997. Sectoral innovation systems: technological regimes, Schumpeterian dynamics, and spatial boundaries. *Systems of Innovation: Technologies, Institutions and Organizations***,** 130-156.

BRUNNERMEIER, S. B. & COHEN, M. A. 2003. Determinants of environmental innovation in US manufacturing industries. *Journal of Environmental Economics and Management,* 45**,** 278-293.

CANTNER, U. & GRAF, H. 2006. The network of innovators in Jena: An application of social network analysis. *Research Policy,* 35**,** 463-480.

CANTNER, U. & GRAF, H. 2008. Interaction Structures in Local Innovation Systems. St. Louis: Federal Reserve Bank of St Louis.

CANTNER, U., MEDER, A. & TER WAL, A. L. 2010a. Innovator networks and regional knowledge base. *Technovation,* 30**,** 496-507.

CANTNER, U., MEDER, A. & TER WAL, A. L. J. 2010b. Innovator networks and regional knowledge base. *Technovation,* 30**,** 496-507.

CARLSSON, B. & STANKIEWICZ, R. 1991. On the nature, function and composition of technological systems. *Journal of Evolutionary Economics,* 1**,** 93-118.

CHAN, J., HAYES, C. & DALY, E. M. 2010. Decomposing Discussion Forums and Boards Using User Roles. *Icwsm,* 10**,** 215-218.

CHANG, P.-L. & SHIH, H.-Y. 2005. Comparing patterns of intersectoral innovation diffusion in Taiwan and China: A network analysis. *Technovation,* 25**,** 155-169.

CHEN, P.-C. & HUNG, S.-W. 2014. Collaborative green innovation in emerging countries: a social capital perspective. *International Journal of Operations & Production Management,* 34**,** 347-363.

CLAUSING, D. & FEY, V. 2004. *Effective innovation*, ASME Press New York.

COOKE, P., URANGA, M. G. & ETXEBARRIA, G. 1997. Regional innovation systems: Institutional and organisational dimensions. *Research Policy,* 26**,** 475-491.

CORSARO, D., CANTÙ, C. & TUNISINI, A. 2012. Actors' heterogeneity in innovation networks. *Industrial Marketing Management,* 41**,** 780-789.

CUERVA, M. C., TRIGUERO-CANO, Á. & CÓRCOLES, D. 2014. Drivers of green and non-green innovation: empirical evidence in Low-Tech SMEs. *Journal of Cleaner Production,* 68**,** 104-113.

DE ALMEIDA, M. F. L., DE MORAES, C. A. C. & DE MELO, M. A. C. 2015. Technology foresight on emerging technologies: Implications for a national innovation initiative in Brazil. *Journal of Technology Management and Innovation,* 10**,** 183-197.

DOLFSMA, W. & LEYDESDORFF, L. 2011. Innovation systems as patent networks: The Netherlands, India and Nanotech. *Innovation: Management, Policy and Practice,* 13.

DOLOREUX, D. 2002. What we should know about regional systems of innovation. *Technology in Society,* 24**,** 243-263.

DOSI, G. & NELSON, R. R. 2010. Technical change and industrial dynamics as evolutionary processes. *Handbook of the Economics of Innovation.* Elsevier.

EBBERS, J. J. & WIJNBERG, N. M. 2010. Disentangling the effects of reputation and network position on the evolution of alliance networks. *Strategic Organization,* 8**,** 255-275.

EISINGERICH, A. B., BELL, S. J. & TRACEY, P. 2010. How can clusters sustain performance? The role of network strength, network openness, and environmental uncertainty. *Research Policy,* 39**,** 239-253.

EMONS, O. 2010a. Innovation and Specialization Dynamics in the Automotive Sector: Comparative Analysis of Cooperation & Application Networks. St. Louis: Federal Reserve Bank of St Louis.

EMONS, O. 2010b. Innovation and Specialization Dynamics in the Automotive Sector: Comparative Analysis of Cooperation & Application Networks. *IDEAS Working Paper Series from RePEc*.

ETZKOWITZ, H. & LEYDESDORFF, L. 1995. The Triple Helix--University-industry-government relations: A laboratory for knowledge based economic development.

ETZKOWITZ, H. & LEYDESDORFF, L. 2000. The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy,* 29**,** 109-123.

FAGERBERG, J. 1994. Technology and international differences in growth rates. *Journal of Economic Literature,* 32**,** 1147-1175.

FALLAH, M. H. & IBRAHIM, S. Knowledge spillover and innovation in technological clusters. Proceedings, IAMOT 2004 Conference, Washington, DC, 2004. 1-16.

FELDMAN, M. P. 1994. *The geography of innovation*, Springer Science & Business Media.

FICHTER, K. 2009. Innovation communities: the role of networks of promotors in Open Innovation. *R&d Management,* 39**,** 357-371.

FLEMING, J. & MARTIN, A. 2007. Facilitating reflective learning journeys in sport cooperative education. *Journal of Hospitality, Sport, Tourism, Leisure and Education,* 6**,** 115-121.

FRITSCH, M. & KAUFFELD-MONZ, M. 2010. The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks. *The Annals of Regional Science,* 44**,** 21.

FRITSCH, M., TITZE, M. & PIONTEK, M. 2018. Knowledge Interactions in Regional Innovation Networks: Comparing Data Sources. St. Louis: Federal Reserve Bank of St Louis.

GAY, B. & DOUSSET, B. 2005. Innovation and network structural dynamics: Study of the alliance network of a major sector of the biotechnology industry. *Research Policy,* 34**,** 1457-1475.

GEISLER, E. 2007. A typology of knowledge management: strategic groups and role behavior in organizations. *Journal of Knowledge Management,* 11**,** 84-96.

GIULIANI, E. 2011. Role of technological gatekeepers in the growth of industrial clusters: Evidence from Chile. *Regional Studies,* 45**,** 1329-1348.

GIULIANI, E. & BELL, M. 2005. The micro-determinants of meso-level learning and innovation: evidence from a Chilean wine cluster. *Research Policy,* 34**,** 47-68.

GOETZE, C. 2010. An empirical enquiry into co-patent networks and their stars: The case of cardiac pacemaker technology. *Technovation,* 30**,** 436-446.

GRAF, H. 2011. Gatekeepers in regional networks of innovators. *Cambridge Journal of*

Economics, 35**,** 173-198.

GRAF, H. & HENNING, T. 2009. Public research in regional networks of innovators: A comparative study of Four East German regions. *Regional Studies,* 43**,** 1349-1368.

GRAF, H. & KRÜGER, J. J. 2011. The Performance of Gatekeepers in Innovator Networks. *Industry and Innovation,* 18**,** 69-88.

GRANOVETTER, M. 1983. The Strength of Weak Ties: A Network Theory Revisited. *Sociological Theory,* 1**,** 201-233.

HACKER, J. V., BODENDORF, F. & LORENZ, P. 2017. A framework to identify knowledge actor roles in enterprise social networks. *Journal of Knowledge Management,* 21**,** 817-838.

HARGADON, A. & SUTTON, R. I. 1997. Technology brokering and innovation in a product development firm. *Administrative Science Quarterly***,** 716-749.

HEATON, A. 1994a. The Chemical Industry. Blackie Academic & Professional. Academic press New York.

HEATON, C. A. 1994b. *The Chemical industry,* London

New York, London

New York : Blackie Academic & Professional, 1994.

HERRMANN, A., TOMCZAK, T. & BEFURT, R. 2006. Determinants of radical product innovations. *European Journal of Innovation Management,* 9**,** 20-43.

HOJNIK, J. & RUZZIER, M. 2016. What drives eco-innovation? A review of an emerging literature. *Environmental Innovation and Societal Transitions,* 19**,** 31-41.

HOWELLS, J. 2006. Intermediation and the role of intermediaries in innovation. *Research Policy,* 35**,** 715-728.

HU, Y., SCHERNGELL, T., QIU, L. & WANG, Y. 2015. R&D internationalisation patterns in the global pharmaceutical industry: evidence from a network analytic perspective. *Technology Analysis & Strategic Management,* 27**,** 532.

HUALLACHÁIN, B. Ó. & LEE, D.-S. 2014. Urban centers and networks of co-invention in American biotechnology. *The Annals of Regional Science,* 52**,** 799-823.

HUANG, S., LV, T., ZHANG, X., YANG, Y., ZHENG, W. & WEN, C. 2014. Identifying node role in social network based on multiple indicators. *PloS one,* 9**,** e103733.

HUMBLE, J. & JONES, G. 1989. Creating a climate for innovation. *Long Range Planning,* 22**,** 46-51.

HUNG, C. L. 2017. Social networks, technology ties, and gatekeeper functionality: Implications for the performance management of R&D projects. *Research Policy,* 46**,** 305-315.

JACKSON, D. J. 2011. What is an innovation ecosystem. *National Science Foundation,* 1.

JAFFE, A. B., TRAJTENBERG, M. & HENDERSON, R. 1993. Geographic localization of knowledge spillovers as evidenced by patent citations. *the Quarterly journal of Economics,* 108**,** 577-598.

JAMALI, D., ZANHOUR, M. & KESHISHIAN, T. 2009. Peculiar strengths and relational attributes of SMEs in the context of CSR. *Journal of Business Ethics,* 87**,** 355-377.

JENKINS, H. 2009. A 'business opportunity'model of corporate social responsibility for small- and medium-sized enterprises. *Business ethics: A European review,* 18**,** 21-36.

K.C. CHEN, J. & KIEN PHAM, V. 2014. A study on knowledge flows of dye-sensitized solar cells' patent. *Foresight : the Journal of Futures Studies, Strategic Thinking and Policy,* 16**,** 229-249.

KC CHEN, J. & KIEN PHAM, V. 2014. A study on knowledge flows of dye-sensitized solar cells' patent. *Foresight,* 16**,** 229-249.

KEMP, R. 1994. Technology and the transition to environmental sustainability: the problem of technological regime shifts. *Futures,* 26**,** 1023-1046.

KEMP, R. & PEARSON, P. 2007. Final report MEI project about measuring eco-innovation. *UM Merit, Maastricht,* 10.

KLEWITZ, J., ZEYEN, A. & HANSEN, E. G. 2012. Intermediaries driving eco-innovation in SMEs: a qualitative investigation. *European Journal of Innovation Management,* 15**,** 442-467.

KRAFFT, J., QUATRARO, F. & SAVIOTTI, P. P. 2011. The knowledge-base evolution in biotechnology: a social network analysis. *Economics of Innovation and New Technology,* 20**,** 445.

KRÄTKE, S. 2010. Regional knowledge networks: A network analysis approach to the interlinking of knowledge resources. *European Urban and Regional Studies,* 17**,** 83-97.

LEE, D.-S. 2014. Urban centers and networks of co-nventon n Amercan botechnology. *The Annals of Regional Science,* 52**,** 799-823.

LEE, K.-H. 2009. Why and how to adopt green management into business organizations? The case study of Korean SMEs in manufacturing industry. *Management Decision,* 47**,** 1101-1121.

LEE, P. C. & SU, H. N. 2010. Investigating the structure of regional innovation system research through keyword co-occurrence and social network analysis. *Innovation: Management, Policy and Practice,* 12**,** 26-40.

LÓPEZ, F. J. D. & MONTALVO, C. 2015. A comprehensive review of the evolving and cumulative nature of eco-innovation in the chemical industry. *Journal of Cleaner Production,* 102**,** 30-43.

LÓPEZ, F. J. D. & MONTALVO CORRAL, C. 2012. *The greening of the chemical industry: past, present and challenges ahead*, Scrivener Publishing.

LUDWIG, J. K. 2017. Green Chemistry: An Introductory Text. Taylor & Francis.

LUNDVALL, B.-Å. 1988. Innovation as an interactive process: from user-producer interaction to national systems of innovation. *Technical Change and Economic Theory*.

LUNDVALL, B.-A., DOSI, G. & FREEMAN, C. 1988. Innovation as an interactive process: from user-producer interaction to the national system of innovation. *1988***,** 349-369.

LUNDVALL, B.-Å. & FORAY, D. 1996. The knowledge-based economy: from the economics of knowledge to the learning economy. *Employment and Growth in the Knowledge-based Economy.*

LUNDVALL, B.-Ä. & JOHNSON, B. 1994. The learning economy. *Journal of Industry Studies,* 1**,** 23-42.

MAGGIONI, M. A. & UBERTI, T. E. 2011. Networks and geography in the economics of knowledge flows. *Quality & Quantity,* 45**,** 1031-1051.

MAGGIONI, M. A., UBERTI, T. E. & USAI, S. 2011. Treating patents as relational data: Knowledge transfers and spillovers across Italian provinces. *Industry and Innovation,* 18**,** 39-67.

MAIRESSE, J. & MOHNEN, P. R&D and productivity: a reexamination in light of the innovation surveys. DRUID Summer Conference, 2003. Citeseer, 12-14.

MANBER, U. 1989. *Introduction to algorithms: a creative approach*, Addison-Wesley Reading, MA.

MANTEL, S. & ROSEGGER, G. 1987. The role of third-parties in the diffusion of innovations: a survey. *Innovation: Adaptation and growth*, 123-134.

MARKARD, J., RAVEN, R. & TRUFFER, B. 2012. Sustainability transitions: An emerging field of research and its prospects. *Research Policy,* 41, 955-967.

MARRA, A., ANTONELLI, P. & POZZI, C. 2017. Emerging green-tech specializations and clusters–A network analysis on technological innovation at the metropolitan level. *Renewable and Sustainable Energy Reviews,* 67, 1037-1046.

MILES, R. E. & SNOW, C. C. 1992. Causes of failure in network organizations. *California Management Review,* 34, 53-72.

MÖLLER, K., PARTANEN, J., RAJALA, A., WESTERLUND, M., RAJALA, R. & SVAHN, S. Role of partnerships and networks in SME innovation and growth. Proceedings of the IMP Conference, Rotterdam, The Netherlands, 2005. Sage Publications.

MONTRESOR, S. & MARZETTI, G. V. 2008. Innovation Clusters in Technological Systems: A Network Analysis of 15 OECD Countries for the Mid-1990s. *Industry and Innovation,* 15, 321-346.

MOODYSSON, J. & JONSSON, O. 2007. Knowledge collaboration and proximity: The spatial organization of biotech innovation projects. *European Urban and Regional Studies,* 14, 115-131.

MU, J., PENG, G. & LOVE, E. 2008. Interfirm networks, social capital, and knowledge flow. *Journal of Knowledge Management,* 12, 86-100.

NERKAR, A. & PARUCHURI, S. 2005. Evolution of R&D capabilities: The role of knowledge networks within a firm. *Management Science,* 51, 771-785.

NOVELLI, M., SCHMITZ, B. & SPENCER, T. 2006. Networks, clusters and innovation in tourism: A UK experience. *Tourism Management,* 27, 1141-1152.

OECD 1999. *Managing National Innovation Systems*.

OECD 2008. Compendium patent statistics. OECD Science, Technology and Industry Working Papers.

POLANYI, M. 2009. *The tacit dimension*, University of Chicago press.

PONDS, R., VAN OORT, F. & FRENKEN, K. 2007. The geographical and institutional proximity of research collaboration. *Papers in regional science,* 86, 423-443.

POPESCU, G. H., COMANESCU, M. & SABIE, O. M. 2016. The role of human capital in the knowledge-networked economy. *Psychosociological Issues in Human Resource Management,* 4**,** 168.

PORTER, M. & VAN DER LINDE, C. 1995. Green and competitive: ending the stalemate. *The Dynamics of the eco-efficient economy: environmental regulation and competitive advantage,* 33.

PORTER, M. E. 2000. Locations, clusters, and company strategy. *The Oxford handbook of economic geography,* 253**,** 274.

PROVAN, K. G. & HUMAN, S. E. 1999. Organizational learning and the role of the network broker in small-firm manufacturing networks. *Interfirm networks: Organization and industrial competitiveness***,** 185-207.

PUCCI, T., RUNFOLA, A., GUERCINI, S. & ZANNI, L. 2018. The role of actors in interactions between "innovation ecosystems": drivers and implications. *IMP Journal*.

REINHARDT, W., SCHMIDT, B., SLOEP, P. & DRACHSLER, H. 2011. Knowledge worker roles and actions—results of two empirical studies. *Knowledge and Process Management,* 18**,** 150-174.

RENNINGS, K. 2000. Redefining innovation—eco-innovation research and the contribution from ecological economics. *Ecological Economics,* 32**,** 319-332.

RENNINGS, K., ZIEGLER, A., ANKELE, K. & HOFFMANN, E. 2006. The influence of different characteristics of the EU environmental management and auditing scheme on technical environmental innovations and economic performance. *Ecological Economics,* 57**,** 45-59.

ROSENBERG, N., LANDAU, R. & MOWERY, D. C. 1992. *Technology and the Wealth of Nations*, Stanford University Press.

SAXENIAN, A. 1996. Regional Networks and Industrial Adaptation in Silicon Valley and Route 128. *Cityscape,* 2**,** 41-60.

SCHIFFAUEROVA, A. 2009. *Knowledge flows in clusters and innovation networks: The case of Canadian biotechnology and nanotechnology.* NR48891 Ph.D., Ecole Polytechnique, Montreal (Canada).

SCHRÖDER, C. 2013. Dynamics in ICT cooperation networks in selected German ICT clusters. St. Louis: Federal Reserve Bank of St Louis.

SCHRÖDER, C. 2014. Dynamics in ICT cooperation networks in selected German ICT clusters. *International Economics and Economic Policy,* 11**,** 197-230.

SHIH-HUNG, C. & WENG, C. S. 2012. The network effect on technological innovation - by the analysis of affiliation network. *Foresight : the Journal of Futures Studies, Strategic Thinking and Policy,* 14**,** 168-178.

STEINER, M., GIL, J. A., EHRET, O., PLODER, M. & WINK, R. 2010. European medium-technology innovation networks: A multi-methodological multi-regional approach. *International Journal of Technology Management,* 50**,** 229-262.

STORPER, M. & VENABLES, A. J. 2004. Buzz: face-to-face contact and the urban economy. *Journal of Economic Geography,* 4**,** 351-370.

STORY, V., O'MALLEY, L. & HART, S. 2011. Roles, role performance, and radical innovation competences. *Industrial Marketing Management,* 40**,** 952-966.

STUART, T. E. 1998. Network positions and propensities to collaborate: An investigation of strategic alliance formation in a high-technology industry. *Administrative Science Quarterly***,** 668-698.

SUN, Y. 2016. The structure and dynamics of intra- and inter-regional research collaborative networks: The case of China (1985-2008). *Technological Forecasting and Social Change,* 108**,** 70.

TER WAL, A. L. J. & BOSCHMA, R. A. 2009. Applying social network analysis in economic geography: Framing some key analytic issues. *Annals of Regional Science,* 43**,** 739-756.

TORRE, A. & WALLET, F. 2014. The role of proximity relations in regional and territorial development processes.

VON HIPPEL, E. 1987. Cooperation between rivals: informal know-how trading. *Research Policy,* 16**,** 291-302.

VON MALMBORG, F. 2004. Networking for knowledge transfer: towards an understanding of local authority roles in regional industrial ecosystem management. *Business Strategy and the Environment,* 13**,** 334-346.

WASSERMAN, S. & FAUST, K. 1994. *Social network analysis: Methods and applications*, Cambridge university press.

WILHELMSSON, P., FRYLAND, L., LINDBLOM, P., SJÖWALL, J., AHLM, C., BERGLUND,

J., HAGLUND, M., HENNINGSSON, A. J., NOLSKOG, P. & NORDBERG, M. 2016. A prospective study on the incidence of Borrelia burgdorferi sensu lato infection after a tick bite in Sweden and on the Åland Islands, Finland (2008–2009). *Ticks and tick-borne diseases,* 7**,** 71-79.

YE, X., ZHANG, J., LIU, Y. & SU, J. 2015. Study on the measurement of international knowledge flow based on the patent citation network. *International Journal of Technology Management,* 69**,** 229.

YOON, J. & PARK, H. W. 2017. Triple helix dynamics of South Korea's innovation system: a network analysis of inter-regional technological collaborations. *Quality and Quantity,* 51**,** 989-1007.

ZACK, M. H. 1999. Managing codified knowledge. *Sloan Management Review,* 40**,** 45.

ZAMYATINA, N. Y. & PILYASOV, A. N. 2017. Concept of proximity: Foreign experience and prospects of application in Russia. *Regional Research of Russia,* 7**,** 197-207.