Distribution and Evolution of Actors' Roles in Knowledge Transfer in Innovation Networks

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Thesis submitted to the
Faculty of Graduate and Postdoctoral Studies
in partial fulfillment of the requirements for the degree of

Master of Science in Management

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Abstract

Collaborative innovation is an important mechanism for firms to exchange and acquire external knowledge. Through collaboration, innovators convene and form networks that, in return, help overcome the boundaries of knowledge transfer. To have a better understanding of actors' collaborating behaviours in innovation networks, we identify three pairs of roles: 1) do actors make connections or bonds with their partners? 2) do actors exchange their knowledge with internal or external partners? 3) do actors absorb or distribute knowledge? We examine the distribution and evolution of actors' roles from these three perspectives by using social network analysis. In this thesis, we use thousands of patent data from the United States Patent and Trademark Office, to investigate the actors' behaviours in the chemical industries of two Canadian regions, i.e. Montreal and Windsor-Sarnia.

Based on the results of our analysis, Montreal, acting as a public-dominated region, shows a more complex distribution of roles, while Windsor-Sarnia with a private orientation indicates a simplex pattern. From the evolution perspective, the network of Montreal is more stable and diversified, with key actors being active in the local network for more extended periods. Unlike Montreal, Windsor-Sarnia faces a higher level of mobility and globalization.

Keywords: Collaborative Innovation; Actor's Roles; Social Network Analysis; Chemistry Industry

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1. Introduction

The ability to continually innovate is a critical factor for the long-term growth of firms, especially in highly-industrialized nations and industries (Dosi and Nelson, 2010). However, modern technologies are becoming increasingly complex. Confronted with explosive growth of knowledge generation and scattered distribution of knowledge, many firms aim to complement their limited internal resources with external resources. In this context, collaborating with other organizations is an essential way for firms to exchange and acquire external knowledge that is different and complementary with their internal resources. Eggers and Singh (2009) define collaborative innovation as the innovating process of using diverse knowledge bases from different organizations and individuals to discover, create, diffuse and apply ideas within and across organizational boundaries. This definition is based on the assumption that the participation of different individuals and organizations with diverse knowledge bases will make a positive contribution to the quantity and the quality of innovating outcomes. Collaborative innovation enables to reduce the costs of accessing new knowledge and accelerate the speed of knowledge transfer (Mu et al., 2008)

In the process of collaborative innovation, different individuals and organizations gradually gather and form an invisible network that, in return, helps to overcome boundaries of knowledge transfer in innovative collaborations, such as geography (Giuliani, 2011). As innovation networks grow, an increasing number of newcomers are absorbed in joining as actors within the network, connected via their shared innovation activities (Nambisan, 2005). To have a better understanding of innovation networks, we investigate the functions of each actor, identify their corresponding roles, and figure out how roles are changing over time.

In this thesis, we employ social network analysis to examine the distribution and the dynamics of actors' roles in innovation networks. Two Canadian regions are selected as case studies, namely the Montreal region and the Windsor-Sarnia region. This thesis has four major sections: first, we will introduce the theoretical background and list the existing gaps. Then, we will describe the data and methodology used in this thesis in detail. The third section will have an overall analysis of data. Lastly, we will discuss the conclusions based on the results.

2. Literature Review

Recent academic literature has approached the topic of inter-organizational collaborations for research and innovation and their regional dimensions from many perspectives. Research on clusters (Saxenian, 1996, Braunerhjelm and Feldman, 2006), innovation ecosystems (Autio and Thomas, 2014), localized knowledge spillovers (Breschi and Lissoni, 2001), and to some extent even the broader literature on open innovation (Chesbrough, 2003) and even open science (Pordes et al., 2007) address related topics.

In this thesis, the focus will be more specifically on innovation networks (Fritsch and Kauffeld-Monz (2010, p2) which distinguishes itself from the above research areas in that is models the explicit relationships between innovation actors. The focus in this thesis thus is on direct relationships between organizations that are targeted towards research and innovation activities, and in which the exchange and transfer of knowledge is a key element.

2.1. Geographical and Non-Geographical Proximity in Collaboration Innovation

In collaboration networks, knowledge transfer refers to a process of communicating and diffusing research results, innovations and knowledge between different individuals, groups or organizations (Rogers, 1995). Paulin and Suneson (2015) indicate that, in collaborative activities of innovation, knowledge transfer is a focused communication that helps recipients of knowledge to have a cognitive understanding, a more excellent absorptive capability and a better application of knowledge. Knowledge transfer stimulates the development of various types of connections between actors and the establishment of innovation networks.

An essential attribute of knowledge is whether it is tacit or codified. Generally speaking, tacit knowledge refers to the knowledge that cannot be translated into a text, picture or video, which can be easily transferred without space or time limit (Lundvall and Foray, 1996). On the contrary, we define the codified knowledge (also called explicit knowledge) as the knowledge that can be transferred via a tangible or intangible media, such as books and videos (Zack, 1999). Apart from the differences in transfer medium, tacit knowledge is further related to personal understanding and the environment it emerges in (Polanyi, 2009). For example, people with different backgrounds and experiences will develop distinct interpretations and understanding of the same knowledge. Based on these essential attributes of knowledge, we can conclude that people are generally able to access explicit knowledge more easily since it is diffused with the use of written documents, largely unhindered by geographical distances or even time limits (Fallah and Ibrahim, 2004). For example, researchers can 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.

Transferring tacit knowledge is generally costly since it requires personal interactions at proximity, such as face-to-face discussion and on-site demonstrations (Bathelt et al., 2004). In the early years, Ryan and Gross (1943) point out that the process of transferring knowledge is also a social process that requires personal contacts. A sophisticated mechanism for transferring tacit knowledge is that geographical closeness motivates and facilities personal contacts and communications, which, in return, develop trustworthy relations in the long term. Such long-term and close communications will help to transfer tacit knowledge in a better and more effective way (Maskell and Malmberg, 1999).

Many researchers emphasize the importance of geographic closeness in innovative collaborations. Boschma (2005) defines 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 can be diffused in a relatively effective manner. Similarly, Agrawal (2003) points out a positive relationship between the geographical proximity and the success of innovating activities. Some empirical evidence has previously indicated that spatial proximity enhances the capability of accessing and exchanging information, thereby reducing the searching costs and uncertainty of entering into a new domain (Feldman, 1994). In addition, geographical proximity accelerates the establishment of innovation networks (Asheim and Isaksen, 2002).

Innovative firms that need external knowledge tend to spatially cluster in the regions with high concentrations of R&D resources, university research and skilled labour (Audretsch and Feldman, 1996). However, in recent years, an increasing number of researchers hold a different view that geography is not the first-order effect to improve the outcomes of innovation activities. Ponds (2007) indicates that geographical proximity is of little relevance for collaborative innovation between academic organizations. Other types of proximity are more critical than geographical proximity in some specific cases. For example, a study by Kuttim (2016) on international collaborations suggests that social proximity and cognitive proximity are more important than the geographical proximity when developing international cooperations.

Table 1 Taxonomy of Proximity in Innovation Activities			
Proximity	Definition	Advantages	Too-Much Dilemma
Cognitive Proximity	the degree of overlap between two actors concerning their knowledge bases	- improve sufficient absorptive capacity to identify, interpret and exploit knowledge from other actors	if two actors' knowledge bases are too similar, the likelihood of an innovative recombination is lower than when dissimilar knowledge bases are merged
Organizational Proximity	the extent to which relations are shared in an organizational arrangement, either within or between organizations	- motivate knowledge exchange - reduce transaction costs	excessive organizational proximity may also hamper interactive learning, as it constrains flexibility
Social Proximity	social embeddedness of actors in terms of friendship, kinship, and experience at the micro-level	- develop trusts to facilitate the exchange of tacit knowledge - reduce, but not eliminate, the risk of opportunistic behaviours	too much social proximity may also be harmful for innovative performance, because of an overload of loyalty and commitment in social relationships
Institutional Proximity	sets of common habits, routines, established practices, rules, or laws that regulate the relations and interactions between individuals and groups at the macro-level - formal institutions: such as laws and rules - informal institutions: such as cultural norms and habits	- provide stable conditions for interactive learning	too much institutional proximity is unfavorable for new ideas and innovations due to institutional lock-in (obstructing awareness of new possibilities) and inertia (impeding the required institutional readjustments)
Geographical Proximity	spatial closeness between organizations	- increase the likelihood that actors will exchange knowledge	a dominance of local linkages may also reduce the innovative performance of a firm (lock-in problem)

Adapted based on *Knowledge networks in the Dutch aviation industry: the proximity paradox* (Broekel and Boschma, 2011, Boschma, 2005)

Boschma (2011, 2005) defines a proximity taxonomy in some of his articles (see Table 1), i.e. cognitive proximity, organizational proximity, social proximity, institutional proximity, and geographical proximity. As an example, institutional proximity highlights the importance of environmental impacts such as regulatory laws, local traditions and social norms. Boschma (2005) points out that different types of proximities are not supposed to be considered in isolation. Furthermore, the degree of proximities should be controlled in a certain range (not too high or too low). For example, if two collaborators have similar knowledge bases, they will exchange and absorb knowledge from each other more effectively. However, if the cognitive proximity is excessive, collaborations will become less meaningful since collaborators are less likely to supplement knowledge from a highly similar knowledge base. Dilemmas exist for all dimensions (see Table 1).

2.2. Regional Innovation Networks

Previous papers have demonstrated that the distribution of innovation activities is not even across regions and countries. In other words, some regions have highly innovative activities, while others show fewer motivations to become innovative (Maraut et al., 2008). Innovative activities present different patterns in space. Many researchers focus on the spatial heterogeneity of innovative activities, answering questions such as where the innovative collaborations centralize and why such a centralization exists. Some typical examples of regional innovation theories are regional innovation systems (Cooke, 2001) and regional patterns of innovation (Capello and Lenzi, 2018).

Regional innovation networks refer to a set of interactive private and public organizations and the milieu to support their innovation activities (Doloreux, 2003). Five factors make a significant contribution to the development of regional innovation networks, i.e. reciprocity, trust, learning behaviours, partnerships and decentralism (Cooke, 1996). The core idea of regional innovation networks is to understand the actors' behaviours within networks, such as actors' characteristics and features of their innovating behaviours. It is worth mentioning that, although regional innovation networks are associated with concepts such as innovation clusters and industrial districts, there are significant differences (Fritsch and Kauffeld-Monz, 2010). Firms in specific industrial districts or clusters can benefit from the public knowledge resources, without proactively establishing collaborative relationships with other firms within that area. In contrast, firms are engaged in a regional innovation network only if they build up collaborative connections directly with other networked members.

Previous papers analyze regional innovation networks mainly from two perspectives, i.e. patterns of innovation activities and evolution. From the innovation activity perspective, Capello and Lenzi (2018) summarize three patterns of regional innovation networks, i.e. a science-based pattern, a creative application pattern and an imitative innovation pattern. For the science-based pattern, the major participators are companies, universities and R&D centers, acquiring knowledge simultaneously from internal and external sources. For the creative application pattern, most of the core knowledge is generated and acquired from external regions. In such regional innovation networks, the primary task of local firms is to absorb external knowledge and employ it in internal innovation applications. There is little scientific knowledge produced locally. In the regions with an imitative innovation pattern, most of the innovation activities are imitating behaviours between dominant firms (which are generally multinational) and other local subcontractors.

From the evolution perspective, Capello and Lenzi (2016) indicate that functional characteristics and relational characteristics of actors are two influential factors. The former factor refers to the change of internal organizations and the informal relationships that facilitate the local learning behaviours. The relational characteristics are concerning local preconditions for maintaining such relationships and long-distance relationships between local actors and other external actors.

2.3. Forms of Knowledge Transfer and Co-Patenting

In collaborative innovation, relationships are established via several forms. Zucker (1998) summarizes three major types of connections: 1) publication and co-authorship, 2) communication with key scientists and inventors, 3) mobility of scientists and inventors. Subsequent papers expand this categorization. For example, co-patents, research contracts and licensing can be added into the first type. Business consulting and (in)formal meetings can be included in the second. Recruiting and personal mobility (not only the scientists and inventors) belong to the third type. Keeble and Wilkinson (1999) suggest a subdivision of the third type including the mobility of labour force within organizations and regions, job-hopping from existing organizations (firms, universities and public research laboratories) to others, and personnel exchange between suppliers and customers, and makers and users.

There are two basic paradigms for knowledge sharing: “proprietary” and “open”. Under the logic of proprietary technology, organizations protect their intermediate research outcomes, tools and methods, e.g. through patent applications or by keeping them as trade secrets. In the research phase, knowledge is generally only transferred among researchers within specific boundaries, in order to obtain feedback and help from colleagues to improve current outcomes. In this case, knowledge transfer across boundaries is limited and rare. Once patents are granted, the proprietary information is made public in exchange for commercial protection from unlicensed use.

In contrast, the open paradigm introduces the sharing mechanism in the public area. The most common way to make technological knowledge available under the open paradigm is its publication in academic and trade journals. Scientists and inventors gather as communities and collaborate with each other, frequently communicating within their community and occasionally across different communities (Partha and David, 1994). Open Innovation (Chesbrough, 2003, Chesbrough and Bogers, 2014) refers more broadly to the collaboration between organizations in the innovation process and is defined as an innovating process that manages knowledge flows across different firms by using pecuniary and non-pecuniary mechanisms. Open innovation may include free sharing by researchers and innovators, but it may also include, for example, licensing of patents between two organizations.

As one of the activities in collaborative innovation, co-patenting has attracted much attention among researcher, especially in studies using quantitative methods due to its accessibility (Cohen et al., 1998). At the macro level, co-patenting networks provide the data of collaborators in patenting activities, allowing researchers to investigate the knowledge transfer during collaborations (Guan and Liu, 2016). Compared with co-authorship and publications, co-patenting is more related to industrial researchers and company partners, considered as the visible outcomes of collaborative innovations in R&D (Goetze, 2010). Patent data can help understand relationships in collaborative innovation and point out the path of knowledge transfer in a comprehensive manner, thus mapping the relationship networks among inventors.

Co-patenting networks generally show a particular tendency of fragmentation at the emerging stage. In other words, collaborative relationships at this stage are not established frequently and repeatedly, and most of the inventors within co-patenting networks are in an isolated status (Goetze, 2010). With the development of co-patenting networks, actors establish their collaboration relationships generally following two principles, i.e. time and preferential attachment. "Time" means the timing when actors enter into the collaborative network. When a local industry emerges, few pioneers choose to participate. They will face a higher risk of failing in this new industry, however, if they survive the start-up period, they will generally earn relatively higher reputation and acquire abundant relationship resources (Haupt et al., 2007). The principle "time" is highly associated with "preferential attachment". Goetze (2010) indicates that innovation actors prefer to collaborate with others who have established many relationships and possessed abundant resources within and outside networks. When patenting networks are in a developed stage, there will exist a large number of inventors with few collaborative relationships and a small number of inventors with excessive relations (Wasserman and Faust, 1994).

2.4. Public Sector and Private Sector in Knowledge Transfer

Collaborative relationships between the private sector and the public sector can facilitate the generation of new knowledge (de Wit-de Vries et al., 2019). On the private side, a lot of graduates and postgraduates pursue their career life in industry after receiving advanced education, which facilitates knowledge transfer from universities to the private sector (Cruz-Castro and Sanz-Menéndez, 2005). Some of the graduates and postgraduates even move back and forth between universities, public laboratories and private laboratories. Hiring professors as companies' consultants, funding university research and participating in collaborative research projects are also good ways to stimulate knowledge transfer between the public sector and the private sector (Audretsch, 2000). Additionally, researchers and professors can transfer their knowledge to industries by legally licensing inventions that are funded publicly or federally (Agrawal, 2001).

One of the analytical frameworks of bridging the public side and the private side is the National Systems of Innovation (Lundvall, 1992, Freeman, 1995), indicating that collaborative innovations are a series of interactive activities involving business enterprises, universities and research institutes. Building on National Systems of Innovation theory, a series of sub-branches are proposed, such as technological innovation systems (e.g. Carlsson and Stankiewicz, 1991), regional innovation systems (e.g. Cooke, 1992), triple helix of innovation (e.g. Etzkowitz and Leydesdorff, 1995), sectoral innovation systems (e.g. Breschi and Malerba, 1997), innovation clusters (e.g. Giuliani and Bell, 2005) and innovation ecosystems (e.g. Jackson, 2011), making contributions to the investigations of collaborative innovation and bridging the public sectors and private sectors.

Public-Private partnerships become increasingly notable in recent years (Chin and Gold, 2017, Achard and Di Berardino, 2018). Azagra-Caro (2016) points out that private-public collaborations play a significant role in moderating, stimulating knowledge transfer to the private sector.

However, different industries show distinct patterns of public-private collaborations. In most industries, private sector actors lead the development of commercially significant inventions with relatively minor or indirect contributions from universities and R&D institutions (Mowery and Sampat, 2004). There is evidence that in the fundamental physics and chemistry, universities and R&D institutions contribute more since the training of scientists and engineers and obtaining experimental techniques are essential in these two fields. Cohen and Nelson (2002) highlight that the chemical industry in particular is an exception in that basic science, on which universities generally focus, is regarded as significant by industry respondents. Therefore, examining public-private partnerships is particularly important in the chemical industry.

2.5. Actor's Roles in Knowledge Transfer

A core idea of regional innovation networks is to understand actors' behaviours within networks, such as their characteristics and features of innovating behaviours (Capello and Lenzi, 2016). Analyzing the roles that key actors are playing provides a valuable perspective to understand regional innovation networks.

Previous studies have identified several roles in innovation networks, from different perspectives and at different levels. For example, Reinhardt (2011) introduces a typology conveying a series of roles according to their functions in innovation networks, i.e. controllers, helpers, learners, linkers, networkers, organizers, retrievers, sharers, solvers and trackers. As another example, the relationship promotor is a typical role of networked innovators, which refers to the individuals who help to develop and motivate the communications within and across organizations (Gemünden and Walter, 1997). Additionally, knowledge gatekeepers have been identified as the role of helping to access external knowledge outside organizational boundaries by informal relationships (Cooney and Allen, 1974). However, definitions and functions of roles' typologies always have overlapped and vague points. For example, the functions of relationship promotor are partially similar to these of knowledge gatekeepers. According to previous papers on actors' roles, we summarize three pairs of roles: 1) exchanging knowledge with internal or external actors, 2) distributing or absorbing knowledge, and 3) bonding or connecting with other networked actors.

2.5.1 Actors' Roles: Do They Exchange Their Knowledge with Internal or External Partners?

Collaborating with internal partners means that actors choose to exchange and cooperate with partners who are located within the same region. Collaborating with external partners is the

Table 2 Selected Examples for Dimension One: Collaborating with Internal or External Partners?

Roles	Definition	Characteristics	Function	References
technical gatekeeper	Individuals who identify external sources, and then interpret and absorb the information and ultimately translate it so that it can become meaningful for internal colleagues	- constitute a small community of individuals - at the core of an information network - overexposed to external sources of information - their linkages with external actors are mostly informal	External; Connecting;	(Tushman and Katz, 1980, Cooney and Allen, 1974, Graf, 2011, Giuliani, 2011, Hung, 2017, Schiffauerova and Beaudry, 2012, Broekel and Mueller, 2018)
knowledge broker	Individuals who facilitate knowledge transfer between groups to which he does not belong.	- well-connected internally and externally - Facilitate communication of other group members - Collect, interpret and translate knowledge	Internal; External; Connecting;	(Brown and Duguid, 1998, Meyer, 2010, Perrin, 2013, Pawlowski and Robey, 2004, Hargadon, 2002, Bornbaum et al., 2015)
boundary spanner	Individuals who are linking the organization's internal networks with external sources of information.	- act as an organization/group representative - linking internal networks and external networks - collect, interpret and translate knowledge - a conceptual role including special examples, such as gatekeeper, Organizational liaisons and Laboratory liaisons	Internal; External; Connecting;	(Tushman, 1977, Marrone, 2010, Nochur and Allen, 1992, Paraponaris et al., 2015, Safford et al., 2017)
power/process/technology promoter	Individuals who help solve the managerial conflicts during the knowledge transfer of innovation	- power: motivate knowledge transfer based on management goal, at a powerful position - process: provide management networking, provide information about experts and human mobility - technology: search for new information, assessment of existing solutions, and generation new alternatives	Internal Connecting	(Hauschildt, 1999, Fichter, 2009, Hauschildt and Kirchmann, 2001)
relationship promoter	individuals who help to develop and motivate the communications within and outside organizations	- an advanced role of process promoter - co-operation with external partners (establish and maintain relationships) - mainly focus on overcome extramural barriers of interactions	External; Connecting	(Walter, 1999, Hauschildt, 1999, Pemartín et al., 2019)

Summarized by author.

opposite. Some roles examples have been shown below (see Table 2). One of the most famous roles in this dimension is gatekeepers, with the common characteristics that most of the roles listed in this part have. Gatekeepers help to communicate internal resources and external knowledge, absorb new knowledge and distribute them within their local networks (Graf, 2011).

2.5.2 Actors' Roles: Do They Learn or Teach Knowledge?

Learning and teaching are the second pair of essential roles, according to Lundvall's assumptions that learning behaviors are necessary actions in innovation network (1994). The direction of learning behaviours can divide all actors into two groups: knowledge learner (adopting) or knowledge teacher (distributing). Some examples have been shown in Table 3.

Table 3 Selected Examples for Dimension Two: Learning or Teaching?

Role	Definition	Characteristics	Function	References
local/global subcontractor	Individuals who have a predominantly "learning" role with other actors within regions or outside	- most of the collaborative innovation relationships are learning/adopting - technological expertise with rich skills - strengthen the learning processes through social context factors, maintaining contacts, or being an active part of a group of connected actors that can trigger joint initiatives and take advantage of emerging or deliberate forms of socialization	Learning; Internal; External	(Pucci et al., 2018)
global/local leader	Individuals who have a predominantly "teaching" role with other actors within regions or outside	- most of the collaborative innovation relationships are teaching others - the object of transfer in interaction processes is technological expertise	Internal; External; Teaching	(Pucci et al., 2018)
knowledge user	Individuals who implement, utilize, adopt, adapt, absorb, and exploit the outcomes, benefits, and impact of knowledge	- users can shift to generators or transmitters - one individual can undertake more than one roles simultaneously	Learning	(Geisler, 2007, Parry et al., 2009)
generator	Individuals who procure, collect, acquire, assemble, prepare and store knowledge from all sources	- generators can shift to users or transmitters - one individual can undertake more than one roles simultaneously	Teaching	(Geisler, 2007, Parry et al., 2009)

Summarized by author.

2.5.3 Actors' Roles: Do They Connect or Bond Their Partners?

In the Cambridge Dictionary, the word "bond" means a close connection joining groups of people. In this paper, it is defined as a role that links significant numbers of partners and has a relatively high reputation and influence in innovation networks, while "connecting" refers to the function providing connections between pairs of influential actors, as a critical bridge to exchange knowledge and information. When identifying this pair of roles, we consider both the number of bonding partners and the times of repeated collaborations (called weight in following parts).

Table 4 Selected Examples for Dimension Three: Connecting vs. Bonding

Role	Definition	Characteristics	Function	References
innovation bridges	Individuals who provide knowledge or services that are complementary to firms	- it can be experts, consulting firms, and so forth.	Connecting	(Czarnitzki and Spielkamp, 2003, Bessant and Rush, 1995, Forti et al., 2013)
knowledge intermediaries	Different definitions such as: Individuals who transfer technology between hosts and users and who facilitate the diffusion of knowledge in a social system of new ideas from external systems	- a variety of different definitions - linking other individuals from outside to inside, from host to user, from producer to market, from big companies to small ones, etc.	Connecting; Internal; External	(Howells, 2006, Watkins and Horley, 1986, Popp, 2000, Cantù et al., 2015, Hayter, 2016)
networker	Individuals who create personal or project related connections with people involved in the same kind of work, to share information and support each other.	- analyze, dissemination, expert search, monitoring, networking, service search	Connecting	(Davenport and Prusak, 1998, Nonaka and Takeuchi, 1995, Reinhardt et al., 2011)

Summarized by author.

2.6. Research Question

Who is engaged in the process of knowledge transfer and what kind of roles they are playing are two critical questions for detecting and understanding collaborative behaviours in innovative activities. However, previous papers have proposed diverse taxonomies of roles, many of which share overlapping or similar functions and characteristics with different names. This thesis seeks to add clarity to literature through integration and rearrangement of actors' roles.

In this thesis, we will examine the distribution and evolution of actors' roles from three different perspectives: 1) do they collaborate with internal or external partners? 2) do they distribute or adopt knowledge? 3) do they bond or connect with their partners? Actors can have a high level of performance in all six dimensions. For example, an actor can link a great number of internal partners and external partners at the same time. The research question of this thesis is: How are actors' roles distributed and evolving in the innovation networks of the chemical industry in two Canadian regions? We will discuss this question based on empirical analysis employing social network analysis.

3. Data and Methodology

3.1. Data

This thesis draws on patent data for the chemical industry to analyse the roles of actors in innovation networks.

3.1.1 Patents and the Chemical Industry

Patents serve to protect the intellectual property rights of inventors in the commercialization process. In essence, patents provide public disclosure of the patented technology in exchange for a time-limited exclusive right to incorporate the technology into commercial products and services. Publicly available patent documents contain detailed descriptions of new products or techniques, they list the inventors and owners including their affiliation and geographic location, and provide time lines for the filing of the application and the issuance of the patent. Additional information includes the classifications to which new products and techniques belong, the titles describing for which purpose this patent is designed, and the keywords that inventors use to define their patent and technology classes (e.g. IPC code, International Patent Classification). As such, there is a long history of patent analysis in innovation studies (e.g. Arundel and Kabla, 1998).

While patents can be considered useful indicators of research output and can form the basis of commercialization, the use of patent data to model innovation also has important limitations. Firstly, not all outputs of innovation collaborations are patented. Factors such as the cost of application, maintenance and potential legal defense of the patents may lead to the absence of patenting (Fritsch et al., 2018). Secondly, the importance and role of patents in the innovation process differs across industries (Arundel and Kabla, 1998). For example, Arundel and Kabla (1998) find that the patenting behaviours of process innovators are less related to industries, but the product innovators are profoundly affected by industry practices. Mairesse and Mohnen (2003) achieve a similar conclusion that patenting is more critical in the manufacturing industry than in the service industry. Innovations and inventions in non-technological sectors tend to be kept confidential, such as new methods for organizational management (Fritsch et al., 2018).

In the chemical industry, because leading firms tend to regard patents as an essential method of protecting intellectual property, especially in bulk organic chemicals and petrochemicals. Many chemical firms have the means to be able to afford the costs of patenting and defending the patents in order to keep their competitiveness (Arora, 1997). Yamaguchi (2016) concludes that the fields with the highest rate of patent applications are chemistry and metallurgy, emphasizing the importance of patenting activities in the chemical industry. In addition, public sources of knowledge take a central role in collaborations in the chemical industry, which suggests that patent data in this industry will allow the modeling of various roles of actors participating in the innovation process (Arora, 1997).

Therefore, we choose to use the patent data of the chemical industry to investigate the actors' behaviours and roles in innovation collaborations.

According to Von Hippel (1987) and Fagerberg (1994), innovative collaborations are networked, complex and sometimes systemic, hence social network analysis (SNA) is a suitable analytical tool in consideration of these characteristics (more details concerning SNA and its methods will be introduced in the methodology part).

SNA focuses on relationships within and outside targeted networks, requiring an enormous quantity of data that are relational and easy to access (Graf, 2011). The data used in SNA may be primary (such as interviews and questionnaires) or secondary data (such as industry reports and patents). However, primary data have some inherent and inevitable shortcomings when we use SNA. SNA requires data to be abundant. That way, networks can be mapped and investigated thoroughly (except for some special networks, e.g. ego network). However, concerning primary data, obtaining on a large scale and in a large quantity is generally challenging, requiring a massive amount of human resources, time and funding. Apart from this, possible low response rates and pre-list of target population probably lead to a potential bias when we consider the overall performance of innovation activities (Ter Wal and Boschma, 2009).

Some previous SNA studies have employed secondary data, such as patent data (e.g. Cantner and Graf, 2006). Patent data have several advantages in SNA. First, patents are easy to access since they are generally published on official websites and downloadable without geographical limits. Also, patents provide a tremendous amount of information on innovation processes. For example, they deliver information about all of the members of innovative teams and core contents of innovation products, across different sectors, regions and fields. Also, patents are relational data that offers opportunities for relational analyses, such as SNA (OECD, 2008). Considering these factors, we tend to adopt patent data as the primary data source.

3.1.2 Data Acquisition

We use the patent data of the chemical industry from the United States Patent and Trademark Office (USPTO), covering the patent documents from 1970 to 2019. In other words, approximately fifty years of patents are gathered in all. Two Canadian regions are selected (i.e. Winder-Sarnia and Montreal) since they are two leading regions with extensive activity in the chemistry industry in Canada. In the process of data selection, two principal criteria are used: 1) patents are chosen if at least one participant is located within selected regions (inventor or applicant); 2) patents must be classified under the chemical industry according to Cooperative Patent Classification (CPC) codes. Based on the principal criteria, the process of data acquisition follows the procedure shown above (see Figure 1).

Figure 1 The Process of Data Acquisition

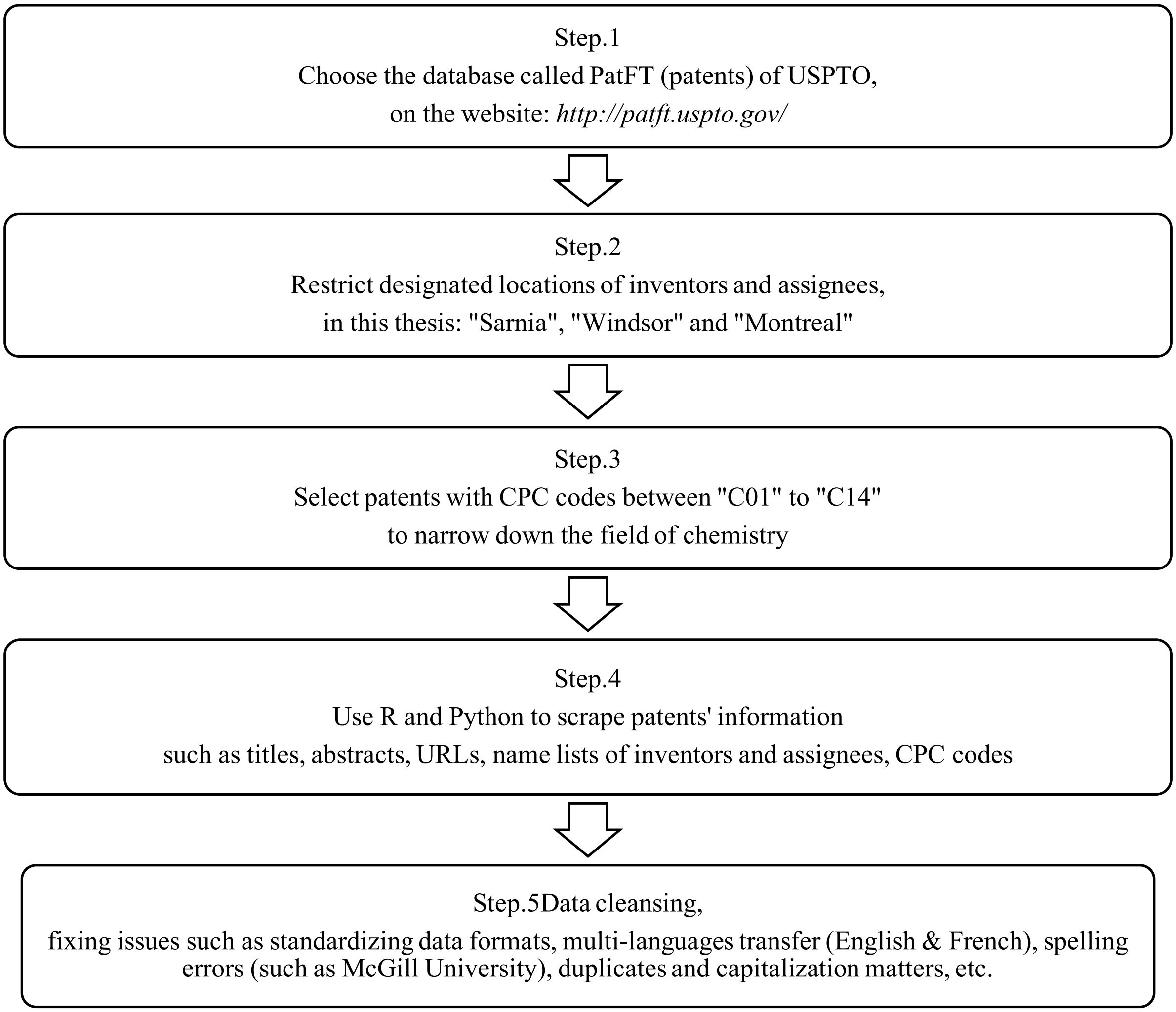


Table 5 Codes for Sub-Fields of Chemistry according to CPC	
Sequence number	Include
C01	inorganic chemistry
C02	treatment of water, waste water, sewage, or sludge
C03	glass, mineral or slag wool
C04	cements, concrete, artificial stone, ceramics, refractories
C05	fertilizers, manufacture thereof
C06	explosives; matches
C07	organic chemistry
C08	organic macromolecular compounds; their preparation or chemical working-up; compositions based thereon
C09	dyes; paints; polishes; natural resins; adhesives; compositions not otherwise provided for; applications of materials not otherwise provided for
C10	petroleum, gas or coke industries; technical gases containing carbon monoxide; fuels; lubricants; peat
C11	animal or vegetable oils, fats, fatty substances or waxes; fatty acids therefrom; detergents; candles
C12	biochemistry; beer; spirits; wine; vinegar; microbiology; enzymology; mutation or genetic engineering
C13	sugar industry
C14	skins; hides; pelts; leather
Summarized from CPC scheme at the official website of USPTO (*https://www.uspto.gov/web/patents/classification/cpc/html/cpc.html*)	

We employ CPC to seek out all patents in the chemical industry. As a popular classification method, CPC covers nine sections and their corresponding sub-classes, having around 250,000 classification entries and managed by the European Patent Office (EPO) and USPTO together. We select the patents whose sequence numbers start with a letter "C" that, based on the CPC scheme, represents the industry of "Chemistry and Metallurgy". More precisely, if digitals in patent numbers after the start letter "C" are between "01" and "14", the corresponding patent is highly associated with the chemical section (more details see Table 5).

In the process of data acquisition, patents with any CPC serial numbers between "C01" to "C14" are scraped from the official website of USPTO. It should be noticed that one patent always has more than one corresponding classification number, which may spread across different sections. For example, the CPC classifications of patent 10,285,296 named "Display panel, fabrication method thereof and display device" cover subclasses of H05, C09, G02 and C08. Among these sub-fields, C08 and C09 belong to the category under the chemistry section, while H05 and G02 are respectively pointing at the subclasses of electric techniques and optics. In this thesis, any patent which has at least one sequence number between C01 and C14 will be regarded under the targeted scope.

After filtering, we collect patent data including 578 assignees, 3935 inventors and 2382 patents in the Montreal region while 473 assignees, 4677 inventors and 3033 patents in the Windsor-Sarnia region. Each patent has possibilities to engage more than one assignee or inventor. Similarly, it is possible to see the same assignee or inventor existing in different patents.

3.1.2 Variables

The variables acquired from patents are shown and briefly explained as below:

Title and Abstract It is defined as a summary of the patented invention, containing many of the relevant words of a patent. A small number of patents do not have a corresponding abstract, but the percentage is not too large to make a significant impact on analysis results.

Patent Number It is defined as a unique number assigned to applications that have issued as patents. The patent number is not always composed of numerical digits, but also letters indicating specialized fields of patents. For example, a patent number with a beginning letter "D" refers to a design patent. It is not very frequent but existing. Each patent only corresponds to one patent number. If any information changed in the documents of one specific patent, a new patent number would be assigned. In this thesis, we use patent numbers as an essential identifier.

Assignee Name/ City/ Country/ State Assignee Name refers to the name of the individual or entity to whom ownership of the patent was assigned at the time of patent issue. In other words, assignees can be individuals, companies, universities, or public institutions. One assignee may have more than one address. Assignee's state is required to provide only when the assignee is located within the US. If the assignee resides outside the US, there will be an assignee's country instead of the assignee's state. For example, the assignees of patent No. 10,285,296 are listed as a form of "BOE Technology Group Co., LTD. (Beijing, CN)" and "Beijing BOE Optoelectronics Technology Co., LTD. (Beijing, CN)".

Inventor City/Country/Name/State They are similar to these of assignees. The only difference is that inventors are always natural persons. For example, “Xiao; Wenjun (Beijing, CN)”.

Cooperative Patent Classification (CPC) It shows the classification to which the patent has been assigned. In this thesis, the CPC sequence number should between C01 to C14, indicating the patents within the chemical field include 14 sub-classes.

Filed Date Filed date is the year, month and date on which this patent is filed. It is used to separate patents into different periods according to their filed years.

Since some of the patents after 2015 are still under the process of examining and have not been officially recorded on the website, the number of patents during this period may be relatively smaller than it should. In this thesis, patents after 2015 are included but only for referencing.

3.2. Methodology

3.2.1. Social Network Analysis
3.2.1.1 Basic Concepts

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 in Table 6). SNA is a quantitative method of analyzing graphs which are composed of nodes (actors) and edges (links) (Granovetter, 1983). By calculating mathematical measures of graphs, SNA can investigate the distribution and the dynamics of overall or partial networks (or clusters), thereby answering questions such as how pairs of actors are related to each other (Chang and Shih, 2005).

In SNA, nodes (actors) generally represent individuals or organizations that are involved in a specific type of activity and links correspond to relationships among actors (Manber, 1989). Links may be directional. For instance, a relationship between a teacher and a student carries a direction of knowledge transfer. To be precise, knowledge is transferred from teachers to students. However, relationships do not always convey a direction. In some collaborative networks, participants have equal status and exchange their knowledge instead of unidirectional distribution. For the directional links, relationships between pairs of actors are equipped with an arrow to symbolize the knowledge flows between actors. There is no arrow for unidirectional links.

Table 6 Fundamental Concepts of SNA

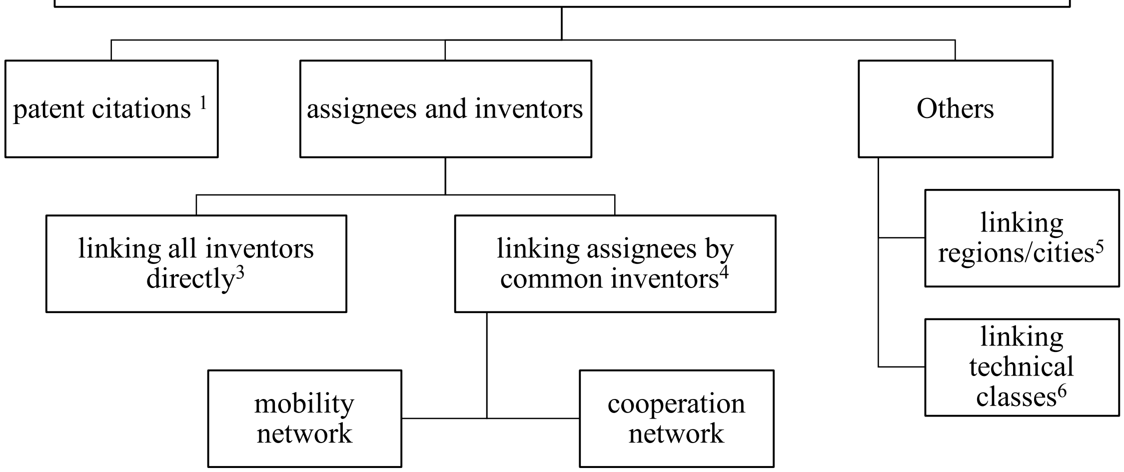
Concepts	Brief Description
Actors (or nodes)	The discrete entities within networks, including individuals, corporates, or collective social units.
Links (or Edges)	A linkage between a pair of actors, including: ⇒ Personal evaluation, e.g. liking or respect ⇒ Transfers of material resources, e.g. business 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)

3.2.1.2 Use of Patent Data in SNA

According to previous papers, there are three principal methods of using different parts of patent data by SNA (Figure 2). The first method is to use citations to map the structure and flows of knowledge in patenting. There are four methods of patent citations analysis used in previous papers: a) direct citations that link 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 which are both cited by a third one, and d) co-citation analysis that provides a more standard process including cited and citing patents (Boyack and Klavans, 2010)

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

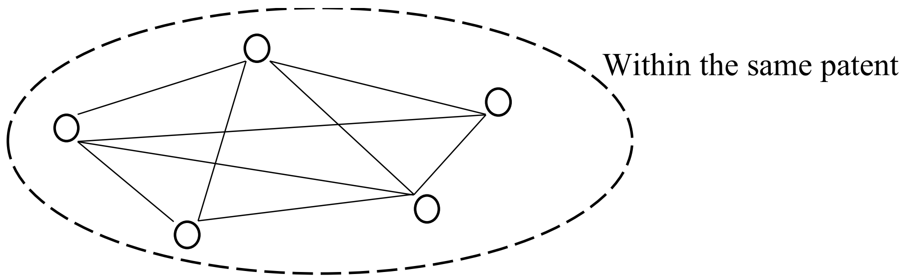


Summarized by author. References:
1. patent citations (Boyack and Klavans, 2010); 2.linking all inventors directly (Balconi et al., 2004); 3. linking assignees by common inventors (Cantner and Graf, 2006); 4. linking regions/cities (Huallacháin and Lee, 2014); 5. linking technical classes (Krafft et al., 2011)

The second method is to use the data concerning on inventors and assignees, based on the assumption that assignees and inventors within the same patent application know each other well (Balconi et al., 2004). Official patent websites document two groups of actors in patenting activities, i.e. assignees and inventors. Assignees may be a private company or a public research institution that hires inventors to innovate (e.g. Schröder, 2014), holding property rights and playing critical roles of exchanging knowledge (Graf, 2011). More precisely, knowledge holders (assignees) can largely decide knowledge diffusion through choosing their innovation partners (Maggioni and Uberti, 2011). Assignees are also called (potential) innovators in some previous papers (Graf and Henning, 2009). Inventors are generally the natural persons who are invited to participate in innovation activities or hired by corresponding assignees. They may be scientists, experts or researchers (Graf and Henning, 2009).

In early studies, inventors are directly linked with all of the other collaborators who are mentioned on the same patents (see Figure 3). Then two sub-variations are proposed, i.e. cooperation network and mobility network (see Figure 4).

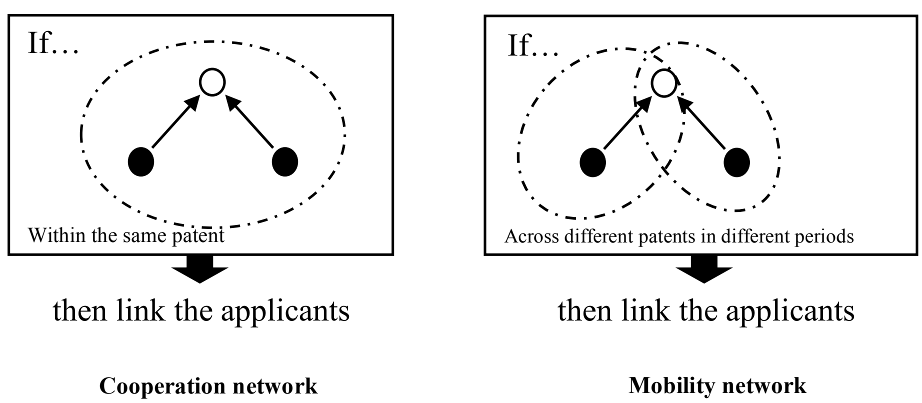
Figure 3 Linking All of Inventors Directly



Tips: Hollow circles represent inventors. Linkages means the existence of collaborative relationships. Dash circle indicates that the actors work within the same patent.

"Cooperation networks" link all co-applying assignees within the same patent as long as they have at least one joint inventor. In this regard, inventors are regarded as the connection (link) between assignees. The more joint inventors the assignees have, the stronger collaborative relationships they have, and the thicker ties will present.

Figure 4 Linking Applicants by Common Inventors

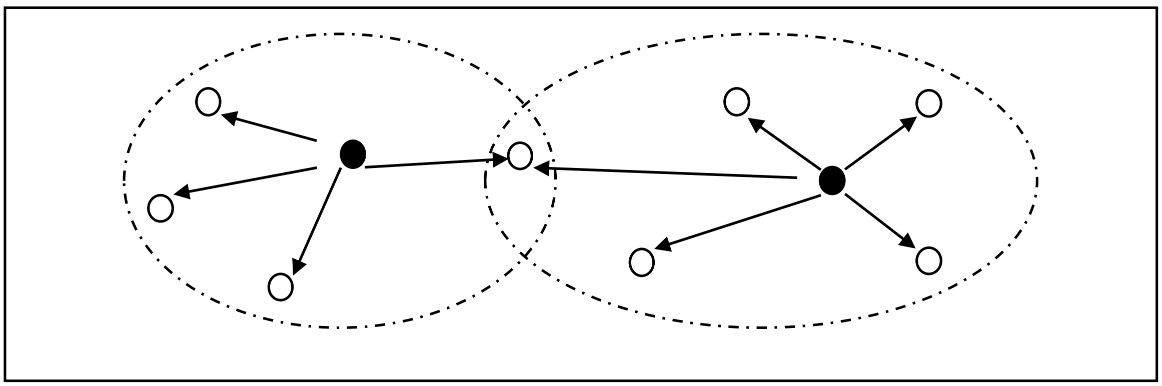


Tips: Solid circles represent assignees and hollow circles represent inventors. Linkages means the existence of collaborative relationships. Dashed circles indicate all of the internal actors are working in the same patent.

"Mobility network" reflects personnel exchanges. If an inventor works for two distinct assignees that are not mentioned within the same patent, these two assignees will be linked (Cantner and Graf, 2006). For example, if an inventor A works for an organization M in the period from 2006 to 2010 and jumps to an organization N in the period from 2011 to 2016, then the organization M and N will be connected in the mobility network. Cooperation and mobility networks both can be interpreted as a possible channel of knowledge flows between inventors' past and present collaborators (assignees) (Graf, 2011). In the empirical analysis of this thesis, two networks are combined and presented in one graph in order to illustrate an overall picture of knowledge transmissions.

Further, an overall network is also presented in this thesis. In the overall networks, assignees are appointed as the start of collaborative relationships, linking all of the inventors who are hired by the corresponding assignees (see Figure 5).

Figure 5 Linking All Persons in Patenting documents



Tips: Solid circles represent assignees and hollow circles represent inventors. Linkages means the existence of collaborative relationships. Dashed circles indicate all actors within this circle are working in the same patent.

The last method of using patents in SNA is to consider technical classes or regions as the nodes in networks (Maggioni et al., 2011). For instance, Huallacháin (2014) connects American cities by co-patenting inventors involved in the industry of biotechnology and maps knowledge flows among those cities. Another example of regarding technical classes as 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 labelled under the same patent application.

3.2.2. SNA Measures

In SNA, centrality measures provide critical perspectives to investigate internal structures of networks at the nodal level (e.g. Lee and Su, 2010). In this thesis, three centrality measures are used to describe regional innovation networks, i.e. degree centrality, betweenness centrality and PageRank.

Degree centrality represents the number of linkages that the specific actor receives or emits. It includes 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 an inventor works for organization A and moves to organization B, then we conclude organization A has one out-degree link, and B has one in-degree link. In this thesis, an actor is defined as playing a teaching role if it has a relatively higher level of out-degree centrality than in-degree centrality. Otherwise, it will act as a learner. The higher degree the centrality is, the more important the corresponding actor is around its network.

The concept of *betweenness centrality* is based on the frequency that a particular actor lies on the shortest link between other pairs of actors. In other words, it examines the actors' ability to control knowledge flows within innovation networks. For example, actor A links actor B, C, D. Actor B links actor C and E. If actor A requires information from actor E, actor B is the shortest path for actor A. To obtain the information more efficiently, actor A is more likely to connect actor B rather than other actors such as C (i.e. A -> C –> B -> E). In this case, actor B has a higher level of betweenness centrality, thus controlling knowledge flows around it better. In other words, if an actor has a higher level of betweenness centrality, this actor will have more control power over the whole network (Krätke, 2010).

The third and last centrality is *PageRank*, which is an algorithm initially used by Google Search to rank web pages in their search engine results. PageRank is a variant of eigenvector centrality, which is designed for measuring the importance of each actor in networks. According to Google, "PageRank works by counting the number and quality of links to a page to determine a rough estimate of how important the website is. The underlying assumption is that more important websites are likely to receive more links from other websites[1]." In this thesis, if an actor has a great number of neighbours who also link other important actors, this actor will have a larger PageRank, thereby becoming a critical actor.

Other than centrality measures, we also calculate the L-P index, I-E index, I-E ratio and N-I index. The L-P index is the proportion of links and patents, indicating the average links for each patent. L-P index has different meanings in different networks. For instance, in overall networks, a higher

[1] "Facts about Google and Competition". Archived from the original on 4 November 2011. Retrieved 12 July 2014.

L-P index means the specific assignee in this network connects many other inventors. However, in mobility networks, the L-P index means the degree of personal mobility for each actor. I-E index is defined as the proportion of the number of internal actors and the number of external actors of the overall network, indicating the degree of being external/internal oriented for the whole innovation networks. Unlike the I-E index, the I-E ratio is designed for individuals. For example, if an actor has three internal links and one external link, the I-E ratio of this actor is three. Lastly, the N-I index is the proportion of the number of national actors and the number of international actors.

3.2.3. Measures of Actors' Roles

The research question of this thesis is: how are actors' roles distributed and evolving in innovation networks in the chemical industries of two Canadian regions. We analyze patent data in two directions: the structure of innovation networks and their evolution.

3.2.3.1 Distributions of Actor's Roles

Three types of networks (i.e. overall network, cooperation network and mobility network) help to visualize the collaborative relationships in innovation activities.

All of the inventors and assignees are divided into four groups: individuals, companies, universities and public institutions. In patent data, most of the inventors are individuals. Assignees who have any keyword indicating the identification of companies in their name will be classified as a company, such as "company", "Inc." and "Ltd.". Public institutions are organizations such as hospitals, research centers and other public departments belonging to governments. Universities are identified in the same way.

In the following steps, three pairs of functions of actors are examined: Do they exchange their knowledge with internal partners or external partners? Do they act as a teacher or learner? Do they play the roles of connecting or bonding?

To measure the ability to collaborate with internal or external actors, we calculate the number of links each actor owns in cooperation networks. All actors are ranked by the number of their internal/external links first. As a further step, two types of actors are separated: internal actors and external actors. For instance, for the Montreal region, any actors locating within Montreal are regarded as internal actors, and other locations represent the status of being external. However, when we analyze the innovation networks in Windsor-Sarnia region, actors locating in Montreal convert to external ones. We select the top-ten actors for each type (internal actors and external actors) and regard them as the key actors with outstanding performance in this dimension.

When it comes to the performances of degree centrality, actors are judged based on how many in-degree/out-degree links they have in mobility networks. As an example, if an inventor works for an assignee A in 1990 and turns to work for another one B in 2000, we define that A has an out-degree link, and B has an in-degree link. All actors within mobility networks will be ranked by in-degree links and out-degree links separately. Given that 20 actors (10 for internal actors and 10 for external actors) are picked in the part of cooperation networks, 20 top actors are chosen as well in this section. The final number of selected actors will be slightly larger than 20 since some actors are sharing the same number of in-degree or out-degree.

In the third dimension of identifying roles, three measures are chosen, i.e. degree centrality, betweenness centrality and PageRank. If the corresponding values of Pagerank and degree centrality are both ranked as top ten among all actors in the cooperation network and the mobility network, actors will be regarded as outstanding in the bonding field. Similarly, if the numbers of Pagerank and betweenness centrality are high enough as the top ten percent, actors are top-ranked of connecting.

After identifying key actors from three perspectives, we conduct a correlation analysis to examine any potential relationships for actors' roles.

3.2.3.2 Evolution of Patent Networks in Chemistry

To gain a more in-depth insight into the evolution of actors' roles during the fifty years considered in this study, we first conduct a keyword analysis for patents' abstracts and titles with the goal of determining relevant segments of analysis.

There are 2382 patent documents for the Montreal region and 3033 for the Windsor-Sarnia region. Following the criteria introduced below, we obtain a list of stopwords to narrow down keywords and gain a better understanding of the patenting trends in the designated regions during the period from 1970 to 2019.

Criteria for stopwords:
1) High-frequency nouns indicating basic descriptions of patents, such as "process", "method" and "product";
2) High-frequency verbs indicating general actions and behaviours in the process of innovating, such as "take" and "operate";
3) High-frequency adjectives and adverbs generally used, not specifically for the chemical industry or green innovation, such as "capable", "complex", "especially" and "generally";
4) Professional terminologies of the chemical industry, such as "heterocyclic", "hyperprolactinemia" and "isoquinoline";
5) Pronouns (such as "our"), prepositions (such as "after"), numbers, punctuation marks (such as "&") and messy code.
6) Combine the same word with different tenses, such as "recycled", "recycle", "recycling".

After eliminating the stopwords that meet the criteria above, we record and rank the top-twenty keywords of each ten years according to their occurrence frequency. Then, we use R to combine the keywords of all years and select the top thirty keywords (see Table 7). For example, for the Windsor-Sarnia region, keywords such as "fuel" and "petroleum" appear more frequently during all years. However, the Montreal region, in a different way, more focuses on the field of pharmaceutics, especially on gene techniques and DNA research in recent decades.

According to these keywords, an apparent split line exists before and after 1990. Therefore, we divide all fifty years into two sub-periods, before 1990 and after. In the next step, keyword clouds for each sub-period are made. The size of keywords is based on their occurrence frequency, in order to render a more intuitive description of differences between two sub-periods.

Table 7 Keyword Analysis of Patents in Montreal and Windsor-Sarnia

Term (Rank by occurrence frequency)	Montreal						Windsor-Sarnia					
	1970s	1980s	1990s	2000s	2010s	total	1970s	1980s	1990s	2000s	2010s	total
pharmaceutical	85	39	47	122	85	378	10			142	99	251
diseases	85		57	151	85	378			31	130	84	245
fuel		10				10	22	83	264	182	35	586
control	21		45	39	21	126	24	88	129	70	43	354
gene	22		152	203	14	391			44		28	72
DNA	14	6	152	203	22	397			27			27
prevention	46		12	38	46	142		19	14	63	28	124
transition	16		20			36		34	46	69	25	174
reduction		44	28			72	23	46	32	33	21	155
waste	16	22	54	20	16	128	30	10	25	17	13	95
cyclic	20		61	34	20	135	9		28	11	16	64
growth	33		29	70	33	165		11		12		23
systems	14		18	23	14	69			30	39	33	102
reformer						0		35	90	56		181
energy	24	10	37		24	95	19	16		25	23	83
drug	18		23	45	18	104				12	19	31
recycling			13			13		56	15	24		95
green	20				20	40	12		30	14		56
cleaning						0			31	29	21	81
purification		7	32	15		54				10		10
environmentally						0		11	13	18	15	57
petroleum						0		20	22			42
regeneration			11			11		36				36
protection						0			36		8	44
quality						0					21	21
efficiency			12			12					7	7
upgrading						0					17	17
degeneration						0					8	8
effluents		7				7						0
emission		5				5						0

Calculated by Author.

Figure 6 Keyword Clouds for Patents in Montreal

Period.1 1970-1989 Period.2 1990-2019

Drawn by author using Voyant tools.

Before 1990, keywords such as “waste” and “reduction” occur more frequently. However, in the following years, the Montreal region confronts a shift to the pharmaceutical industry. It is often to find keywords such as “gene” and “DNA” in the Montreal region after 1990 (as shown in Figure 6). A similar pattern also emerges in the Windsor-Sarnia region (see Figure 7). Except common keywords such as “fuels” and “energy”, patents of Windsor-Sarnia are more concerned about topics, such as “waste”, “recycle” and “reduction” in the first period. However, the focus gradually switches to topics such as “transition”, “reformer” and “prevention” then. Besides, the Windsor-Sarnia region is not a cluster only focusing on energy and fuel anymore after 1990. Keywords such as “diseases” and “gene” start to appear in the list of keywords.

Based on the findings from this keyword analysis, we divide all years into two periods. To have a more in-depth insight into when key actors enter and quit from local networks, we describe the changes of each five years within each period. Results from these analyses, including the evolution in the two regions are presented below.

Figure 7 Keyword Clouds for Patents in Windsor-Sarnia

Period.1 1970-1989

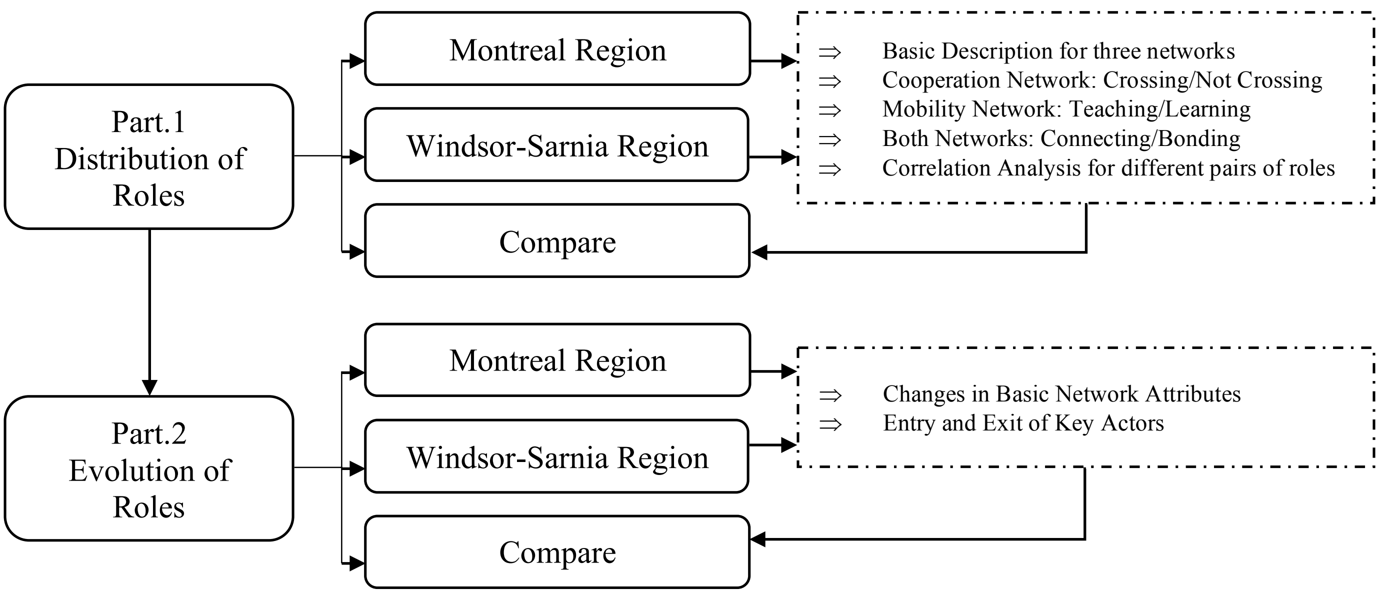
Period.2 1990-2019

Drawn by author using Voyant tools.

4. Results

According to a report of Chemicals and Chemical Products by the Government of Canada (2011), the chemical industries of both Ontario and Quebec play a central role in Canada, with over fifty percent of all chemical establishments in Canada. Windsor-Sarnia, located in Ontario, is the most concentrated chemical cluster in Canada, mainly focusing on chemical and biochemical productions as well as petroleum refineries over the past years (2019a). In Quebec, the Montreal region has the majority of chemical practitioners, more explicitly focusing on chemical pharmaceuticals and medicines sectors (2019b). In this part, we select Windsor-Sarnia and Montreal as two regions and conduct further analyses of the distributions and evolutions of actors' roles (Process see Figure 8).

Figure 8 Analysis Outline



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4.1. Case Backgrounds

In general, Montreal and Windsor-Sarnia have similar total numbers of patents, respectively 3829 for the Windsor-Sarnia region and 3676 for Montreal. Historically, the Windsor-Sarnia region starts a dramatic growth five years earlier than the Montreal region does, and has a stable development after 1980. In comparison, the Montreal region faces a different pattern, emerging relatively late but developing at a rapid speed since the 1990s (see Table 8).

Table 8 Distributions of Patent Sub-Fields in Chemical Industry for Both Regions												
	Montreal						Windsor-Sarnia					
	1970s	1980s	1990s	2000s	2010s	Total	1970s	1980s	1990s	2000s	2010s	Total
C01	24	34	70	63	67	258	27	47	51	81	30	236
C02	19	14	24	30	19	106	8	18	27	29	27	109
C03	5	9	10	2	4	30	14	60	45	31	11	161
C04	6	20	21	18	28	93	14	35	41	28	28	146
C05	0	1	1	3	1	6	0	1	6	5	1	13
C06	12	7	3	0	1	23	0	0	3	1	0	4
C07	227	135	416	681	390	1849	121	170	249	323	251	1114
C08	24	38	112	118	69	361	141	261	208	215	131	956
C09	6	18	47	47	23	141	29	75	60	90	90	344
C10	9	18	12	20	24	83	59	156	156	66	38	475
C11	8	2	5	3	3	21	1	5	18	16	19	59
C12	5	20	231	306	138	700	2	19	65	51	72	209
C13	1	0	0	0	2	3	1	1	0	0	1	3
C14	0	1	1	0	0	2	0	0	0	0	0	0
Total	346	317	953	1291	769	3676	417	848	929	936	699	3829

Calculated by Author.

Tip: It should be noticed that the total numbers of patents for each period are different from those listed in the tables of the next part since it is possible that a single patent owns more than one class.

4.1.1 The Montreal Region

Quebec is the second-largest player in the Canadian chemistry industry, only after Ontario, even if it has faced an apparent decline in the industry's GDP after 2004, from $4.1 billion in 2004 to 3.21 billion in 2014. Recently, the report of "Québec Sectoral Profile 2015-2017: Chemical Manufacturing" indicates a transition of the local business model that shifts from in-house research and development (R&D) to external collaborations with other companies (2019b). During the period from 2008 to 2012, Quebec's chemical industry is in a turbulent stage, facing a series of issues such as entry of new competitors and industrial restructuration on a large scale. However, after 2012, industrial conditions start to recover and rise again. Table 8 shows that the Montreal region has a particular focus on the field of both organic chemistry (C07) and biochemistry (C12).

Organic chemistry is showing consistent growth since the year of 1970, while biochemistry proliferates after 1990.

4.1.1.1 Overall Networks

Table 9 Basic Statistics for Overall Network (Montreal)

Measures		Count	Percentage
Number of Actors		4513	
Patent Category	Assignee	578	12.81%
	Inventor	3935	87.19%
Type of Actor	University	59	1.31%
	Company	460	10.19%
	Individual	3941	87.33%
	Public Institution	53	1.17%
Regional Distribution	Internal	1136	25.17%
	External	3377	74.83%
	I-E index	0.34	
Global Distribution	National	3247	71.95%
	International	1266	28.05%
	N-I index	2.56	
Number of Links		6858	
Number of Patents		2382	
L-P index		2.88	

Calculated by author.

From 1970 to 2019, the Montreal region had 2382 patents in the chemical industry, describing patenting activities among 4513 actors at both an individual level and an organizational level (Table 9). Unlike inventors, assignees account for a smaller proportion of the total population (12.81%). The overall network in Montreal has 25.17 % of internal actors, located within the Montreal region, and about 74% of external actors, participating in patent activities from other cities or countries. Here, the I-E index is 0.34. In other words, there is only one internal actor in every four actors involved in Montreal's overall network.

With regards to the location distributions, 72% of actors are within Canada (including within Montreal and out of Montreal) and less than 30 percent are international actors locating outside Canada. More specifically, around 47% of actors are located outside Montreal but within Canada. Figure 9 (the graph on the right side) shows that the number of red links is much larger than that of orange links, indicating that trans-regional collaborations are much more usual than intra-regional collaborations.

As mentioned in the methodology part, three graphs are drawn to visualize regional innovation networks of Montreal and Windsor-Sarnia. Figure 9 shows the overall networks of Montreal, indicating different types of actors in different colours. In the left graph, red actors stand for universities, orange ones for business companies, green ones for public institutions and yellow ones for individuals. If two actors in different regions collaborate within the same patent, they will be linked via red links. If not, links will be coloured orange. The thickness of links is determined by how many times two actors have collaborated. The more times the actors collaborate, the stronger the links between them will be. The graph on the right side is different from the left one in the colour coding for actors. Actors within Montreal are assigned red and outside is orange. The size of actors is decided by the column of knowledge flows passing by.

Figure 9 Overall Networks of Innovation in Montreal

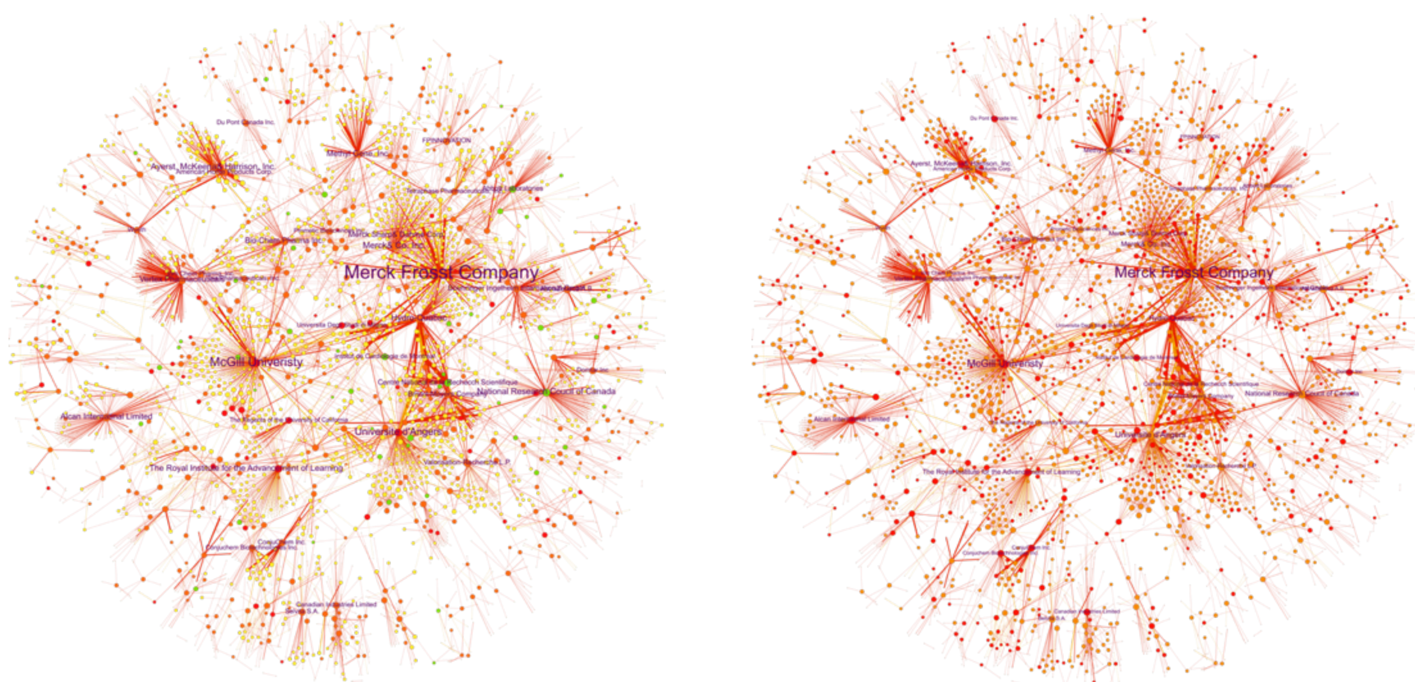

Illustration:
The left graph: actors: green for public institutions, red for universities, orange for companies, yellow for individuals; links: red for cross-regional links, orange for not cross-regional links
The right graph: actors: red for internal actors, orange for external actors; links: red for cross-regional links, orange for not cross-regional links

Figure 9 shows that influential actors in Montreal are mainly companies, universities and public institutions. In other words, most of the key actors are assignees rather than individual inventors. McGill University (Canada) and Angers University (France) are taken as two examples of universities that emerge as influential actors in the overall network. Public institutions also have some key representatives, for example, the National Center for Scientific Research (France). Acting as an important type of actor, companies such as Merck Frosst Company (Canada) and Valorisation-Recherche L.P (Canada) show large sizes in figures.

Figure 9 indicates a pattern that companies are more likely to collaborate with individuals rather than other companies. Differently, the identification of collaborators of public institutions and universities is composed of diverse sources. For instance, McGill University links plenty of companies, public institutions and other universities that also have diverse connections in addition to McGill University. The company Merck Frosst, in contract, has a different pattern in which most connections are with individual inventors who may be employees or consultancy experts.

4.1.1.2 Mobility Network and Cooperation Network

Table 10 Basic Statistics for Mobility Network and Cooperation Network (Montreal)

Measures		Mobility network		Cooperation network	
		Count	Percentage	Count	Percentage
Number of Actors		342		147	
Type of Actor	University	39	11.40%	33	22.45%
	Company	255	74.56%	87	59.18%
	Individual	9	2.63%	2	1.36%
	Public Institution	39	11.40%	25	17.01%
Regional Distribution	Internal	107	31.29%	29	19.73%
	External	235	68.71%	117	79.59%
	I-E index	0.46		0.25	
Global Distribution	National	230	67.25%	77	52.38%
	International	112	32.75%	70	47.62%
	N-I index	2.05		1.1	
Number of Links		522		191	
Mean of Degree Centrality		3.05		2.29	
Mean of Betweenness Centrality		105.99		70.15	

Calculated by Author.

In Montreal, the mobility network has 342 actors, more than twice the number of cooperation networks. The total number of assignees in Montreal is 578 (shown in Table 9 of overall networks).

In other words, there are 236 isolated actors in the mobility network and 411 in the cooperation network. Also, connections of the mobility network are much more than these of the cooperation network. The mobility network has 522 links, and the cooperation network has 191. To be more specific, there are 1.526 links per actor in the mobility network and 1.144 links in the cooperation network. It is safe to conclude, instead of cooperating within the same patent, people are more likely to transfer knowledge through working for different organizations.

Seventy percent of actors involved in the mobility network is external to the Montreal region, and 67 percent of those are from other regions in Canada. In other words, there is 30 percent of actors located within Canada, 36 percent in other provinces of Canada and 32 percent for international actors. A similar distribution exists in the cooperation network, as well. In a word, most of the actors of the Montreal network come from external regions. Other Canadian provinces are a vital source of collaborators for Montreal's actors.

Figure 10 Mobility Network and Cooperation Network in Montreal

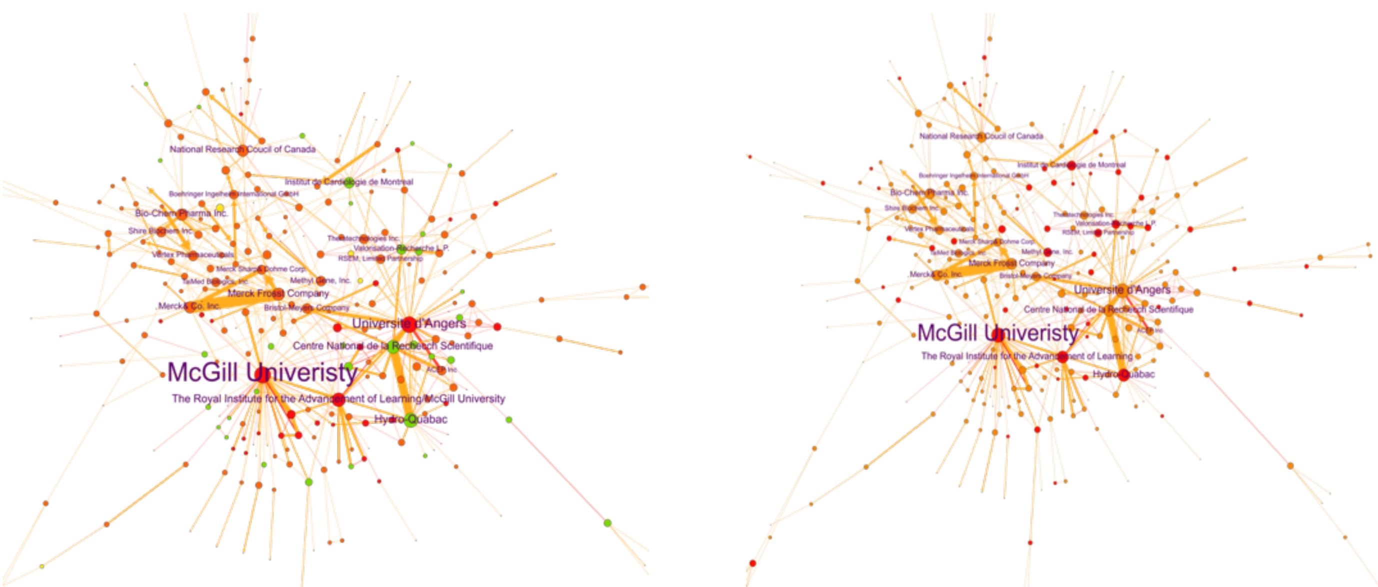

Illustration:
The left graph: actors: green for public institutions, red for universities, orange for companies, yellow for individuals; links: red for cross-regional links, orange for not cross-regional links
The right graph: actors: red for internal actors, orange for external actors; links: red for cooperation links, orange for mobility links

Figure 10 shows the mobility network and cooperation networks for Montreal. The left graph has two types of links, i.e. orange for mobility relationships and red for cooperation. The right graph is similar to overall networks introduced in the last section, with links showing locations of involved actors. Mobility networks and cooperation networks provide a more straightforward way to understand innovating activities in Montreal.

The majority of collaborative assignees are companies in the Montreal region. However, in terms of the influences of each actor, universities (red actors) and public institutions (orange actors) also play an essential role. It should be emphasized that public institutions tend to collaborate with other public institutions and universities rather than other companies (shown at the bottom-right corner of the left graph in Figure 10). Companies are more likely to collaborate with other companies, as shown at the top-left corner of the left graph in Figure 10.

4.1.2 The Windsor-Sarnia Region

Ontario is the province with the largest chemical manufacturing sector in Canada, with over 40 percent of the total production of all Canadian chemistry (2019a). Windsor-Sarnia region is the most concentrated cluster of chemistry in Ontario. As shown in Table 8, the Windsor-Sarnia region has a noticeable increase in the field of glass and mineral (C03), organic macromolecular compounds (C08), and dyes, paints, polishes and natural resins (C09) during all fifty years, while the subsector of petroleum and gas (C10) faces a slight decline after 2000. Organic chemistry (C07) gradually becomes a popular subsector even if growing slightly later than in Montreal.

4.1.2.1 Overall Networks

Windsor-Sarnia region has 5150 actors, including 473 assignees and 4677 inventors. The pattern of the Windsor-Sarnia region is different from the Montreal region. More specifically, most of the influential actors in the Windsor-Sarnia region are companies, such as Bristol-Meyers Squibb Company. It is rare to see universities or public institutions acting as an important one in the overall network of Windsor-Sarnia. According to Table 11, there are only 37 universities and 12 public institutions during all years, accounting for less than one percent of the total population of actors (including assignees and inventors). Compared with the Montreal region, the Windsor-Sarnia region has a relatively monotonous pattern that takes the form of companies acting as a center linking all other individual inventors.

Table 11 Basic Statistics for Overall Network (Windsor-Sarnia)			
Measures		Count	Percentage
Number of Actors		5150	
Patent Category	Assignee	473	9.18%
	Inventor	4677	90.82%
Type of Actor	University	37	0.72%
	Company	422	8.19%
	Individual	4679	90.85%
	Public institution	12	0.23%
Regional Distribution	Internal	932	18.10%
	External	4218	81.90%
	I-E index	0.22	
Global Distribution	National	1159	22.50%
	International	3991	77.50%
	N-I index	0.29	
Number of Links		6749	
Number of Patents		3033	
L-P index		2.23	
Calculated by Author.			

At the regional level, 932 internal actors within the Windsor-Sarnia region and 4218 external actors contribute an I-E index of 0.22. From an international perspective, more than 75 percent of the actors involved in this network come from other countries. Actors from other Canadian provinces only account for 4.4 percent of the total population in the Windsor-Sarnia network. Besides, the L-P index is 2.23, which means each patent has more than two inventors on average.

Figure 11 Overall Networks of Innovation in Windsor-Sarnia

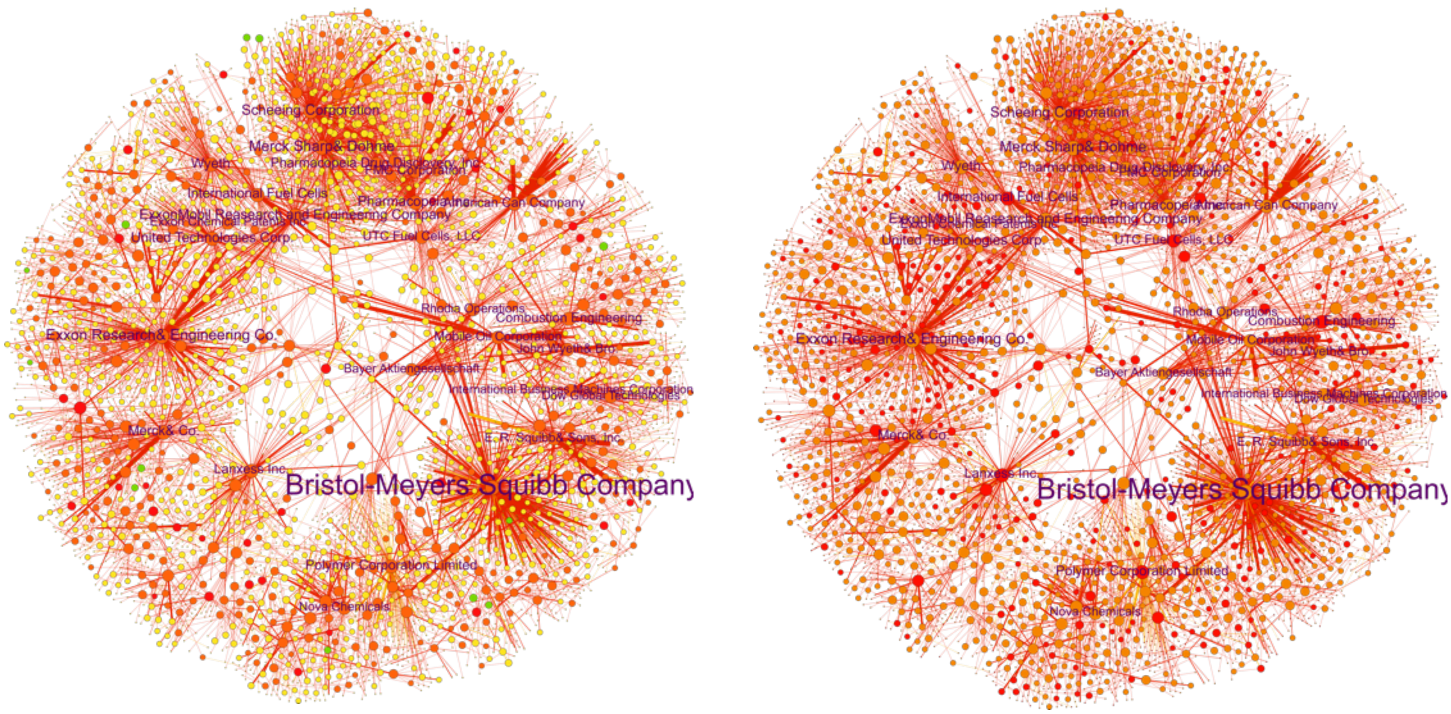

Illustration:
The left graph: actors: green for public institutions, red for universities, orange for companies, yellow for individuals; links: red for cross-regional links, orange for not cross-regional links
The right graph: actors: red for internal actors, orange for external actors; links: red for cross-regional links, orange for not cross-regional links

4.1.2.2 Mobility Network and Cooperation Network

The mobility network and the cooperation network show a similar pattern as the overall network, in that public institutions and universities are rare in the innovation activities of the Windsor-Sarnia region. More precisely, twenty-four universities (8.78%), seven public institutions (88.00%) and two individuals (9.73%) are engaged in the mobility network. A similar distribution is not as extreme but still exists in the cooperation network.

Table 12 Basic Statistics for Mobility Network and Cooperation Network (Windsor-Sarnia)					
Measures		Mobility network		Cooperation network	
		Count	Percentage	Count	Percentage
Number of Actors		275		97	
Type of Actor	University	24	8.73%	19	19.59%
	Company	242	88.00%	75	77.32%
	Individual	2	0.73%	0	0.00%
	Public Institution	7	2.55%	3	3.09%
Regional Distribution	Internal	30	10.91%	4	4.12%
	External	245	89.09%	93	95.88%
	I-E index	0.12		0.04	
Global Distribution	National	42	15.27%	17	17.53%
	International	233	84.73%	80	82.48%
	N-I index	0.18		0.21	
Number of Links		329		73	
Mean of Degree Centrality		2.39		1.46	
Mean of Betweenness Centrality		34.14		1.47	
Calculated by Author.					

The I-E index is relatively low, indicating a small number of internal actors engaged in the regional innovation network of Windsor-Sarnia. Unlike in Montreal, external actors in Windsor-Sarnia are mainly locating out of Canada (82.48%). In particular, the cooperation network only has four internal actors, taking around four percentages of the total. The internal actors are Bayer Inc., Lanxess Inc., the Institute for Chemical Science and Technology and the University of Windsor. From the global perspective, national actors of both networks together do not account for over 20 percent, which means the majority of actors are coming from other countries.

For the Windsor-Sarnia network, companies account for a greater proportion than universities and public institutions. In addition, external and international actors are the major composition of the regional innovation network.

Figure 12 Mobility Network and Cooperation Network in Windsor-Sarnia

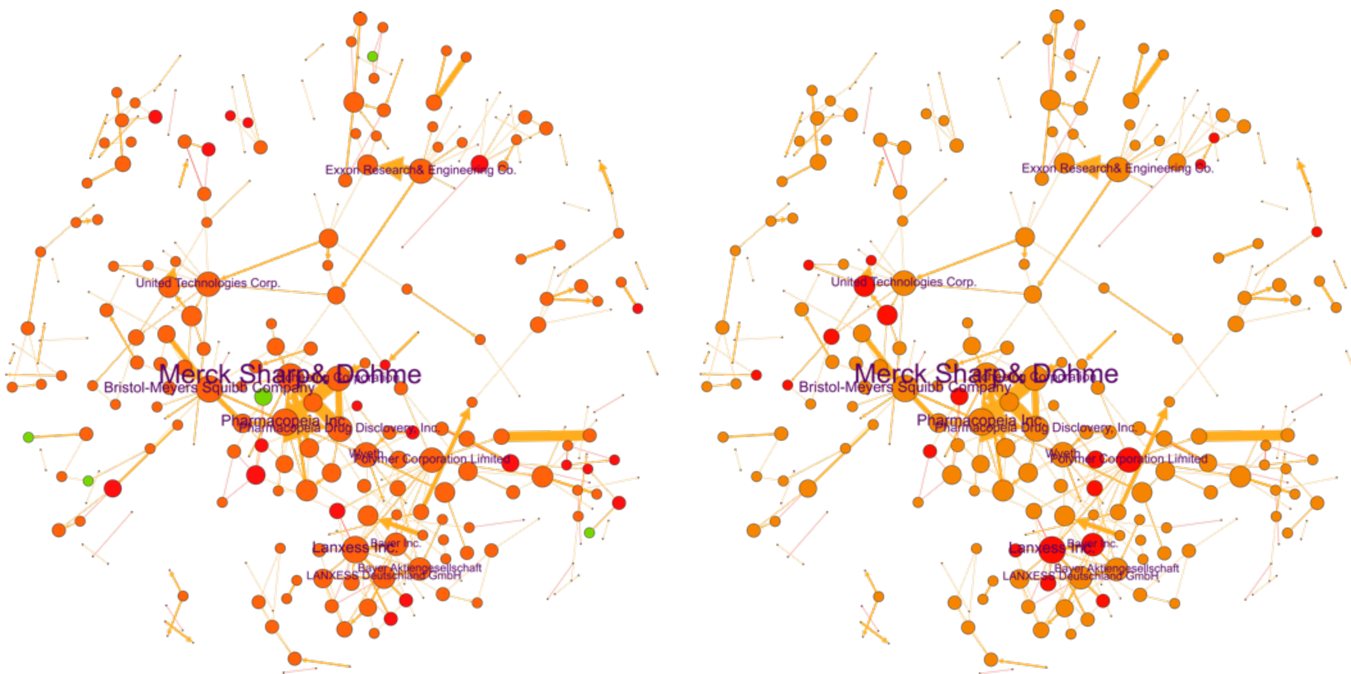

Illustration:
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The right graph: actors: red for internal actors, orange for external actors; links: red for cooperation links, orange for mobility links

4.2. Distributions of Actor's Roles

4.2.1 The Montreal Region

4.2.1.1 Actors' Roles: Do Actors Collaborate with Internal or External Partners?

In the cooperation network, 29 internal actors establish 158 external links and 55 internal links (see Table 13). On average, each internal actor has more than five external links and approximately two internal links. The actor with the most external links is McGill University, which collaborates with 47 other actors in its patenting activities. Hydro-Quebec, as a public institution, occupies the highest number of internal links in the cooperation network. On the other side, the influential external actors in the cooperation network include a large percentage of universities and public institutions, such as Angers University and the National Center for Scientific Research.

I-E ratio is different from I-E index, defined as the ratio of internal links and external links that each actor holds. I-E ratio of internal actors is larger than that of external actors, indicating that internal actors are more likely to collaborate with other internal actors. Among external actors, National Center for Scientific Research (France) has the largest number of external links (75), and Angers University, with most internal links, has 17.

Table 13 Dimension One: Internal & External (Montreal)

	Within Montreal	Outside Montreal
Number of actors	29	117
External links	158	464
Mean of external links per actor	5.45	3.97
Internal links	55	62
Mean of internal links per actor	1.90	0.53
Mean of I-E Ratio	0.45	0.24
Largest number of external links	47	75
Largest number of internal links	10	17
Largest I-E ratio	3	8
Calculated by Author.		

In the scatter plot of internal links against external links (Figure 13), there are three types of actors existing, i.e. externally-oriented actors, internally-oriented actors, and balancing actors. Externally-oriented actors have more external links than internal links have. For example, National Center for Scientific is an externally-oriented actor while the Royal Institute for the Advancement of Learning is a relatively internally-oriented actor. Actors such as McGill University and Angers University have an excellent performance on both sides, acting as a bridge between internal actors and external partners.

Figure 13 Scatter Plot of Internal Links vs. External Links (Montreal)

Drawn by author.

Table 14 Distributions for Top-10 Actors in Dimension One (Montreal)

Montreal			Outside of Montreal		
	Top_internal	Top_external		Top_internal	Top_external
University	10.00%	20.00%	University	50.00%	30.00%
Company	60.00%	40.00%	Company	20.00%	50.00%
Public institution	30.00%	40.00%	Public institution	30.00%	20.00%
Individual	0%	0%	Individual	0%	0%

Calculated by Author.

To identify key actors in the cooperation network of Montreal, we select top ten actors from the lists of both internal actors (Montreal) and external actors (out of Montreal) separately. By comparing the internal group and the external group, it can find that among internal actors, public institutions have relatively larger percentages (30% for top_internal and 40% for top_external) than among external actors. For external actors, the percentages of universities largely increase to

50% and 30% respectively. However, no matter among internal actors or external actors, there are no outstanding individuals. Besides, French actors are an important group collaborating with Montreal's actors based on the list of top actors. There are 3 French actors in the top-internal list and 5 in the top-external list, most of which are universities and public institutions.

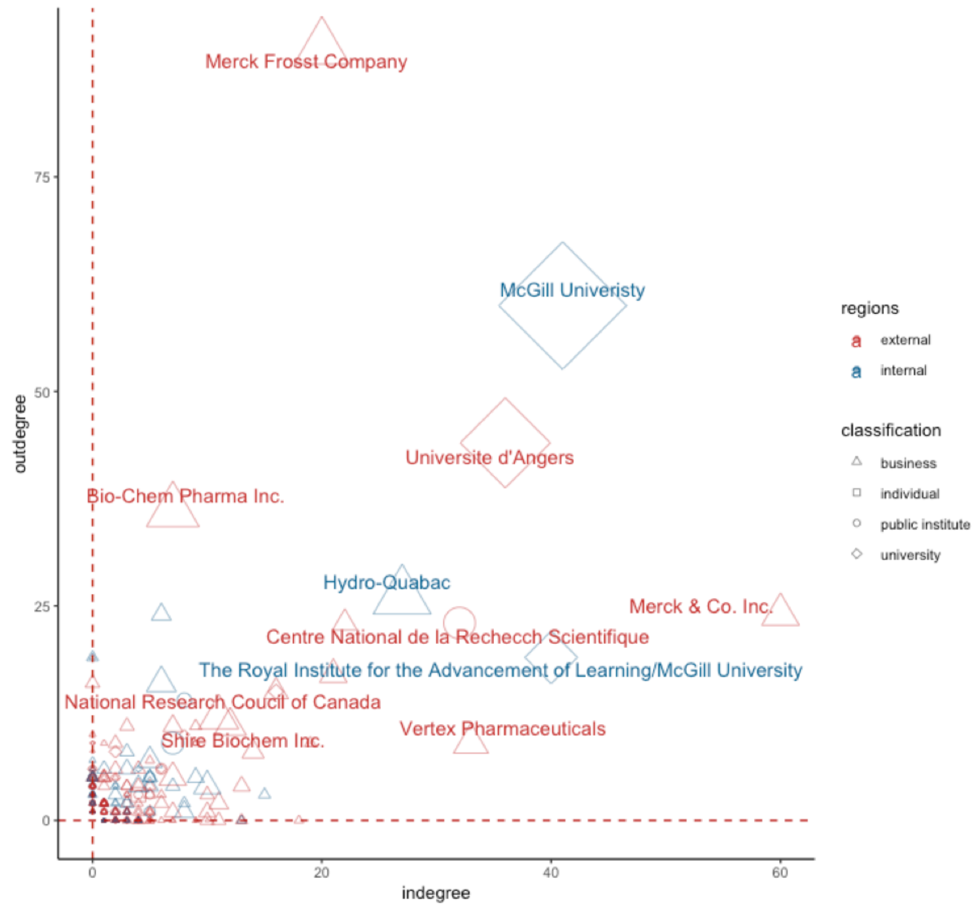
4.2.1.2 Actors' Roles: Do they learn or teach knowledge?

Table 15 Dimension Two: In-degree & Out-degree (Montreal)

Number of links	522
Number of actors	342
Number of out-degree	1812
Average for out-degree	5.30
Number of in-degree	1693
Average for in-degree	4.95
Top 5 Actors with most out-degree	Top 5 Actors with most in-degree
Merck Frosst Company (90)	Merck & Co. Inc. (60)
McGill University (60)	McGill University (41)
Angers University (44)	The Royal Institute for the Advancement of Learning (40)
Bio-Chem Pharma Inc. (36)	Angers University (36)
Hydro-Quebec (26)	Vertex Pharmaceuticals (33)
Calculated by Author.	

In the mobility network, 342 actors constitute 522 connections, 5.2 out-degree links, and 4.9 in-degree links per actor. If including isolated actors, each actor has, on average, 3.13 out-degree links and 2.93 in-degree links. In this thesis, an actor plays a teaching role if it has a relatively higher out-degree centrality than in-degree centrality. Otherwise, it acts as a knowledge learner. In the Montreal region, the actor with most out-degree links is Merck Frosst Company. Merck Co. Inc. is the best learner in the mobility network of Montreal.

Figure 14 Scatter Plot of In-degree and Out-degree (Montreal)



Drawn by author.

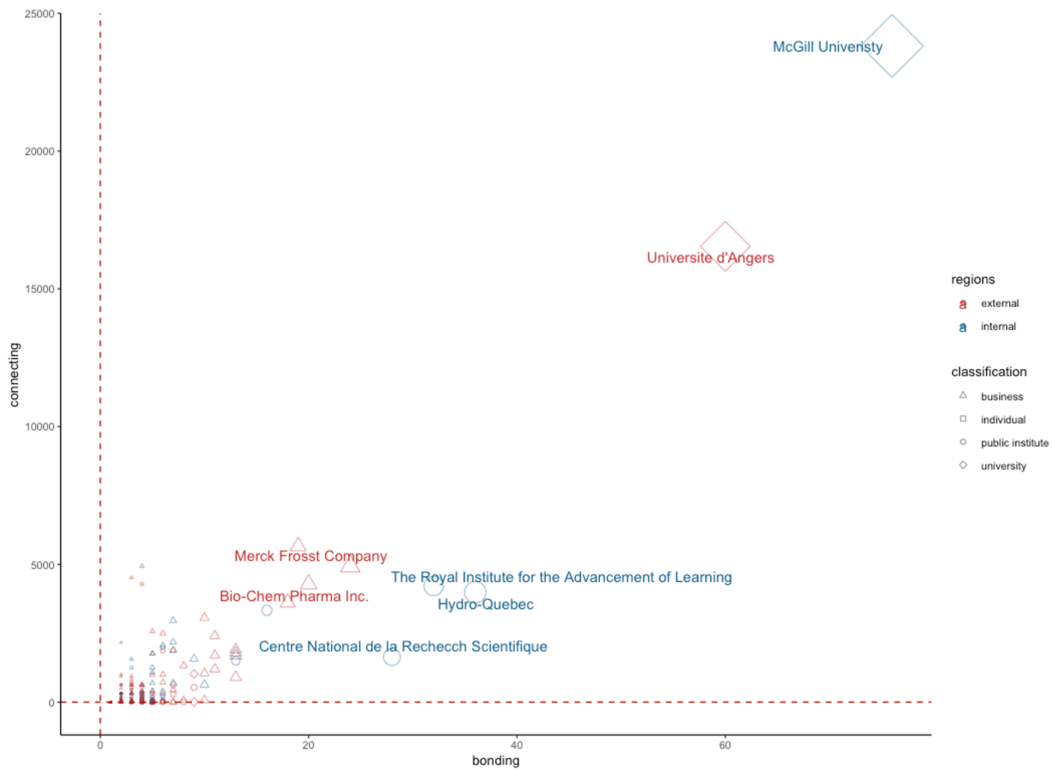
At the macro level, the distribution patterns are highly similar in both lists of top distributors and top adopters (Table 15). Most of the top-ranked actors are companies, and no individuals exist. The percentage of public institutions is slightly lower than that of universities. Although the number of universities and public institutions is not as high as that of companies in the top list, most of the top-five actors are mainly universities and public institutions. In other words, universities and public institutions do not have an advantage in quantity, but their influences over the mobility network are similar to that of companies. It should be noticed that the actor with most in-degree/out-degree is Merck Frosst. In general, students work for different professors during their education and then will be hired by companies. Taking into account this situation, universities have advantages in distributing knowledge and establishing out-degree relationships. However, it is not the whole truth based on our data. Some hypothesizes are proposed. For example, graduates may move to other regions or find a job in other cities. Alternatively, students may change their focus from chemistry to other fields after graduation. Figure 14 shows a potential relationship between in-degree links and out-degree links, indicating that if an actor has a high number of out-degree links, it will have a larger probability of having more in-degree links.

Table 16 Distributions for Top-20 Actors in Dimension Two (Montreal)

Top Out-degree			Top In-degree		
Measures	Count	Percentage	Measures	Count	Percentage
Top_out-degree	23		Top_in-degree	23	
Max out-degree	90		Max in-degree	60	
Min out-degree	11		Min in-degree	11	
University	4	17.39%	University	4	17.39%
Company	17	73.91%	Company	18	78.26%
Individual	0	0.00%	Individual	0	0.00%
Public institution	2	8.70%	Public institution	1	4.35%
Internal actor	8	34.78%	Internal actor	5	21.74%
External actor	15	65.22%	External actor	18	78.26%

Calculated by Author.

4.2.1.3 Actors' Roles: Do They Connect or Bond Their Partners?



At the bonding level, most of the top-ranked actors are companies, of which 60 percent are external actors, and 40 percentages are internal actors. The top-ranked actors at the connecting level indicate a different pattern that more internal actors have great performances (see Table 17). However, no matter at the bonding level or the connecting level, universities and public institutions always play a critical role in Montreal. According to Figure 15, a high level of degree centrality always makes a companion of the high level of betweenness centrality. Among all actors in the cooperation network and the mobility network, two universities have a noticeable influence over all others, i.e. McGill University and Angers University.

Table 17 Distributions for Top-10% Actors in Bonding or Connecting (Montreal)					
Bonding			Connecting		
Measures	Count	Percentage	Measures	Count	Percentage
Top_bonding	30		Top_connecting	27	
Max degree centrality	76		Max betweenness centrality	23812.08	
Min degree centrality	7		Min betweenness centrality	1195.32	
University	5	16.67%	University	3	11.11%
Company	21	70.00%	Company	21	77.78%
Individual	0	0.00%	Individual	0	0.00%
Public institution	4	13.33%	Individual	3	11.11%
Internal actor	12	40.00%	Internal actor	15	55.56%
External actor	18	60.00%	External actor	12	44.44%
Top 5 Actors with most bonding function			Top 5 Actors with most connecting function		
McGill University			McGill University		
Angers University			Angers University		
Merck Frosst Company			Hydro-Quebec		
The Royal Institute for the Advancement of Learning			The Royal Institute for the Advancement of Learning		
Hydro-Quebec			Centre National de la Rechecch Scientifique		
Calculated by Author.					

4.2.1.4 Correlation Analysis for Actors' Roles

This section will answer the question of whether different roles are associated with each other, and if yes, to which degree they are related? Based on Table 18, there are 22 actors in the lists of both top-bonding and top-connecting. Nevertheless, only four actors have outstanding performances in terms of linking internal links and having many in-degree links. The top-five actors in six dimensions are highly similar in Montreal, always including actors McGill University, Angers University, National Center for Scientific Research and Hydro-Quebec.

Table 18 Common Key Actors among Six Dimensions (Montreal)						
	bonding	connecting	external	internal	out-degree	in-degree
bonding	30					
connecting	22	27				
external	14	10	20			
internal	10	6	11	20		
out-degree	16	13	9	5	23	
in-degree	15	12	8	4	13	23
Calculated by Author.						

Table 19 Correlation Analysis and P-values (Montreal)						
r(P)	bonding	connecting	external	internal	out-degree	in-degree
bonding	1.00	0.00**	0.02**	0.93	0.01**	0.05*
connecting	0.72**	1.00	0.17	0.16	0.02**	0.07*
external	0.29**	0.18	1.00	0.01**	0.42	0.80
internal	0.01	-0.18	0.33**	1.00	0.16	0.05**
out-degree	0.32**	0.30**	0.11	-0.18	1.00	0.02**
in-degree	0.25*	0.23*	0.03	-0.25**	0.30**	1.00

a=0.05**; a=0.1*; spearman analysis
Calculated by Author.

To further analyze the relationships between each pair of roles, Table 19 shows the results of Spearman correlations. Most of the roles are related to each other at a significance level of 0.05 or 0.1. Other than the relationship between "in-degree" and "internal" takes on a negative trend, most correlations are positive. For instance, if an actor has a great number of internal links, it will have a relatively higher possibility to own fewer in-degree links. On the other side, if an actor has an excellent performance on the bonding perspective (degree centrality), it will be more likely to have a better connecting function (betweenness centrality). More specifically, if an actor collaborates with more other actors, it will have a better controlling ability over innovation networks.

4.2.2 The Windsor-Sarnia Region

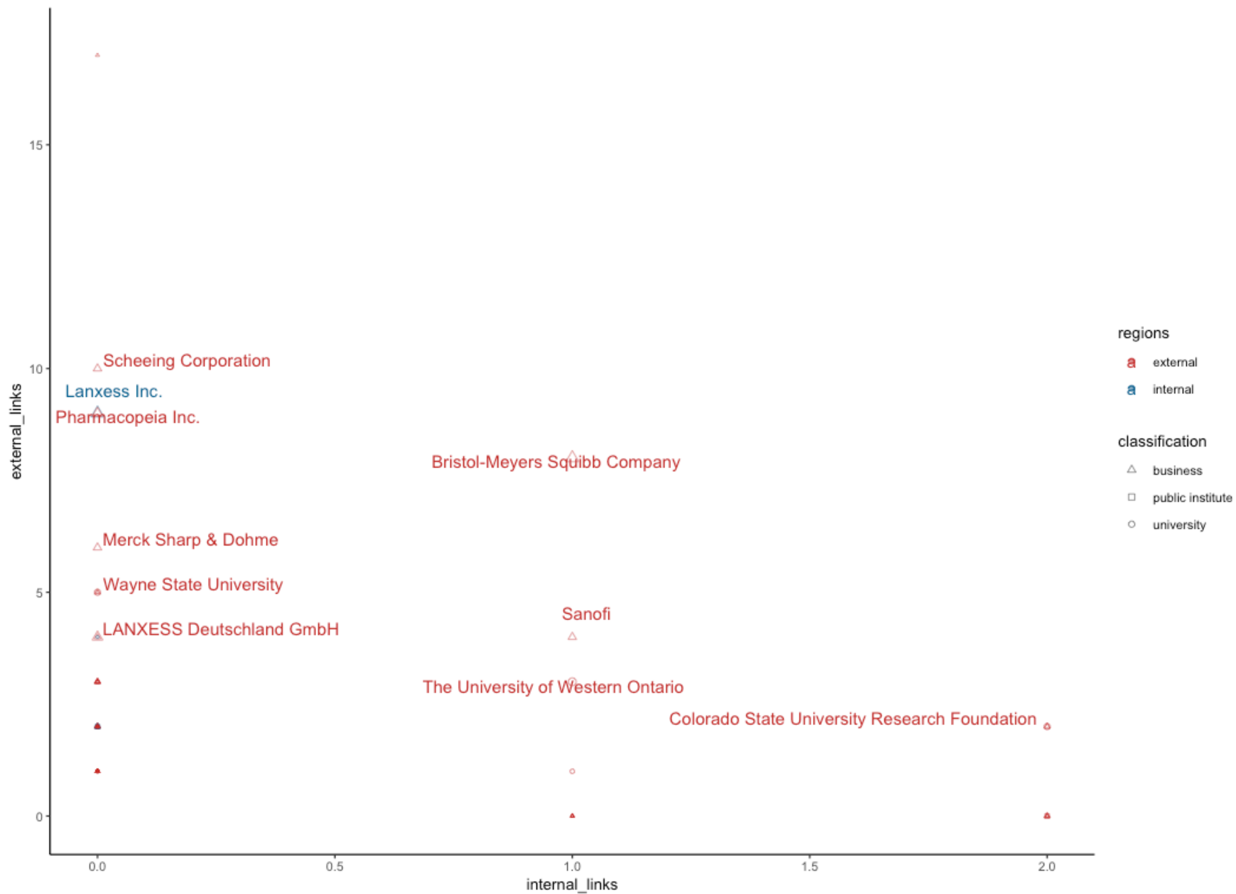
4.2.2.1 Actors' Roles: Do Actors Collaborate with Internal or External Partners?

Table 20 Dimension One: Internal & External (Windsor-Sarnia)		
	Within Windsor-Sarnia	Outside Windsor-Sarnia
Number of actors	4	93
External links	19	186
Mean of external links per actor	4.75	2
Internal links	0	26
Mean of internal links per actor	0	0.28
Mean of I-E Ratio	0	Inf.
Largest number of external links	9	17
Largest number of internal links	0	2
Largest I-E ratio	0	Inf.

Calculated by Author.

In the cooperation network of Windsor-Sarnia, there are only four internal actors, consisting of 19 collaborative links, namely 4.75 per actor (see Table 20). The actor with most external links is Lanxess Inc., which has a Canadian subsidiary located within the Sarnia region. But no internal actor has established any collaborative relationship with other local actors. External actors are more active in the Windsor-Sarnia region, bringing about 186 external links and 26 internal links.

Figure 15 Scatter Plot of Internal Links vs. External Links (Windsor-Sarnia)



Drawn by author.

Actors within the cooperation network have a tendency to be internally-oriented or externally-oriented. For instance, the Scheeing Corporation has a lot of external links but very few internal ones. It is rare to see an actor performing well on both sides in Windsor-Sarnia (locating in the diagonal line of Figure 16).

Only four internal actors are locating within Windsor-Sarnia, who are respectively a university (the University of Windsor), a public institution (the institute for chemical science and technology) and two companies (Lanxess Inc. and Bayer Inc.). Among external actors, over 80 percent of the total actors are companies. Australia (AU) and the United States (New Jersey, NJ) are two locations from which a lot of external actors come, especially for external universities and public institutions. For example, Colorado State University and Wayne State University are both identified as top-ranked actors coming from the United States. It should be noticed that, although Wayne State University is located in the United States, the geographical distance between Windsor and Detroit (Wayne State University) is very close. The only public institution is an industrial research organization, locating in Australia.

Table 21 Distributions for Top-10 Actors in Dimension One (Windsor-Sarnia)

Windsor-Sarnia			Outside of Windsor-Sarnia		
	Top_internal	Top_external		Top_internal	Top_external
University	0%	25.00%	University	10.00%	10.00%
Company	0%	50.00%	Company	80.00%	90.00%
Public institution	0%	25.00%	Public institution	10.00%	0%
Individual	0%	0%	Individual	0%	0%
Calculated by Author.					

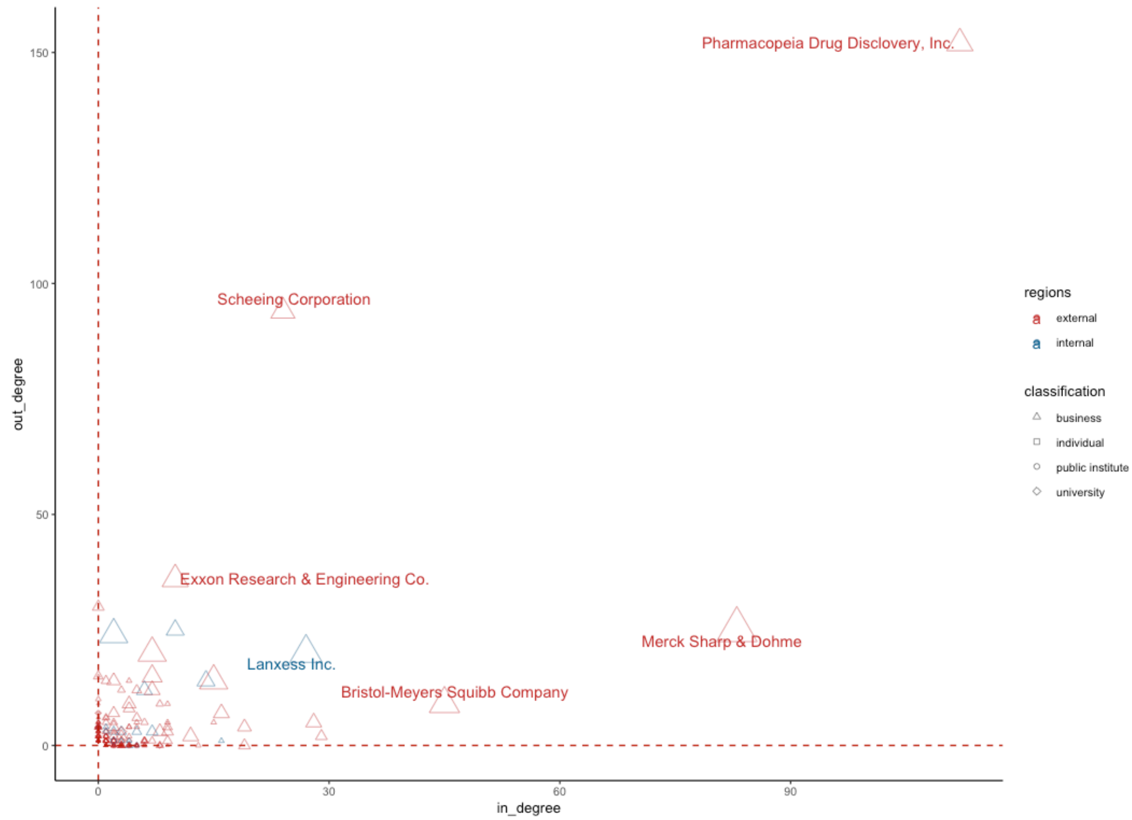
4.2.2.2 Actors' Roles: Do They Learn or Teach Knowledge?

The mobility network contains 275 actors and 329 relationships. Based on Table 22, top-20 actors in in-degree and out-degree lists are all companies, most of which come from other regions.

Table 22 Dimension Two: In-degree & Out-degree (Windsor-Sarnia)

Number of links	329
Number of actors	275
Number of out-degree	1496
Average for out-degree	5.44
Number of in-degree	1521
Average for in-degree	5.53
Top 5 Actors with most out-degree	**Top 5 Actors with most in-degree**
Pharmacopeia Drug Discovery, Inc. (152)	Pharmacopeia Drug Discovery, Inc. (112)
Scheeing Corporation (94)	Merck Sharp & Dohme (83)
Exxon Research & Engineering Co. (36)	Bristol-Meyers Squibb Company (45)
UTC Fuel Cells, LLC (25)	Dendron Corporation (29)
Merck Sharp & Dohme (25)	ExxonMobil Research (27)
Calculated by Author.	

Figure 16 Scatter Plot of In-degree vs. Out-degree (Windsor-Sarnia)



Drawn by author.

According to Figure 17, actors show a potential trend to locate in the diagonal line, but not very centralized. Further relationships need to be detected by correlation analysis in the next section. Top-five companies who come from other regions are mainly focusing on fuel products (such as Exxon Research & Engineering Co.) and pharmaceutical science (such as Merck Sharp & Dohme, and Pharmacopeia Drug Discovery Inc.)

Table 23 Distributions for Top-20 Actors in Dimension Two (Windsor-Sarnia)					
Top Out-degree			Top In-degree		
Measures	Count	Percentage	Measures	Count	Percentage
Top_out-degree	21		Top_in-degree	23	
Max out-degree	152		Max in-degree	112	
Min out-degree	14		Min in-degree	10	
University	0	0.00%	University	0	0.00%
Company	21	100.00%	Company	23	100.00%
Individual	0	0.00%	Individual	0	0.00%
Public institution	0	0.00%	Public institution	0	0.00%
Internal actor	5	23.81%	Internal actor	4	17.39%
External actor	16	76.19%	External actor	19	82.61%

Calculated by Author.

4.2.2.3 Actors' Roles: Do They Connect or Bond Their Partners?

Figure 17 Scatter Plot of Degree Centrality vs. Betweenness Centrality (Windsor-Sarnia)

Drawn by author.

Among the top-22 actors, there is only one university (the University of Western Ontario). All other actors are companies. The difference between the largest degree centrality and the smallest degree centrality is not as huge as Montreal's, meaning that the overall level of degree centrality is relatively lower in Windsor-Sarnia. Besides, the gap of degree centrality between each couple of actors is not as high as that of Montreal.

Table 24 Distributions for Top-10% Actors in Bonding or Connecting (Windsor-Sarnia)					
Bonding			Connecting		
Measures	Count	Percentage	Measures	Count	Percentage
Top_bonding	22		Top_connecting	21	
Max degree centrality	22		Max betweenness centrality	4681.03	
Min degree centrality	6		Min betweenness centrality	276.80	
University	1	4.55%	University	0	0.00%
Company	21	95.45%	Company	21	100.00%
Individual	0	0.00%	Individual	0	0.00%
Public institution	0	0.00%	Public institution	0	0.00%
Internal actor	5	22.73%	Internal actor	5	23.81%
External actor	17	77.27%	External actor	16	76.19%
Top 5 Actors with most bonding function			Top 5 Actors with most connecting function		
Merck Sharp & Dohme			Wyeth		
Pharmacopeia Inc.			American Home Products Corp.		
Lanxess Inc.			Polymer Corporation Limited		
Bristol-Meyers Squibb Company			United Technologies Corp.		
Scheeing Corporation			Pharmacopeia Inc.		
Calculated by Author.					

4.2.2.4 Correlation Analysis for Actors' Roles

It is relatively rare for Windsor-Sarnia's actors to play multiple roles. In other words, functions of actors in Windsor-Sarnia region are more separate than in Montreal. Actors shouldering more than one role are all company actors.

Table 25 Common Key Actors among Six Dimensions (Windsor-Sarnia)						
	bonding	connecting	external	internal	out-degree	in-degree
bonding	22					
connecting	19	21				
external	7	5	20			
internal	4	3	2	20		
out-degree	13	14	3	2	21	
in-degree	14	12	7	4	8	23
Calculated by Author.						

Based on Table 26, if an actor has a high level of bonding capability, it will have a good connecting function as well. Except for the role of linking internal actors, bonding is more or less associated with other role's functions. As a role that is highly related to bonding, connecting has potential and negative relationship with the ability to link internal links. In other words, if an actor has reasonable knowledge control over networks, it will be less likely to have many internal links. Besides, the ability to link internal actors is generally negatively related to the extent of having out-degree links and in-degree links, which means if an actor holds a lot of internal links, it will be less likely to face a high level of personal mobility.

Table 26 Correlation Analysis and P-values (Windsor-Sarnia)

r(P)	bonding	connecting	external	internal	out-degree	in-degree
bonding	1.00	0.00**	0.05*	0.12	0.02**	0.02**
connecting	0.89**	1.00	0.23	0.05*	0.00**	0.04**
external	0.27*	0.17	1.00	0.59	0.68	0.08*
internal	-0.22	-0.27*	-0.08	1.00	0.00**	0.09*
out-degree	0.33**	0.43**	-0.06	-0.40**	1.00	0.47
in-degree	0.33**	0.29**	0.25*	-0.24*	-0.10	1.00

a=0.05**; a=0.1*; spearman analysis
Calculated by Author.

4.2.3 Comparison

The basic statistics tell a story that, although there are more actors in Windsor-Sarnia than in Montreal, the total number of collaborative links is similar. Besides, the numbers of actors and links within the mobility and cooperation network are generally higher in Montreal, indicating a more prosperous picture of innovative activities. Besides, although most of the actors in both regions are companies, Montreal has more universities and public institutions serving as important roles.

In cooperation networks, the Montreal region has more internal actors, while Windsor-Sarnia only has four. Unlike Montreal, Windsor-Sarnia is more externally-oriented not only because it has less internal actors, but also because all actors of the Windsor-Sarnia region tend to collaborate with other external collaborators. For instance, internal actors of Windsor-Sarnia only establish 19 external links and no internal links. Additionally, key actors of Montreal and Windsor-Sarnia show different levels of performances in six dimensions. Taken as an example, in Montreal, the top actor that links the most of external links has 47 connections, while the best one in Windsor-Sarnia only has 9. The range from the maximum to the minimum is more extensive in Montreal, indicating the abilities among distinct actors have vast differences.

The mobility networks of two regions show a similar pattern as the cooperation networks do. The Windsor-Sarnia region has more external actors, companies and international actors locating outside of Canada. However, the distribution of key actors is different between the two regions. Windsor-Sarnia is a region with more companies as key actors, while in Montreal, key actors tend to be universities and public institutions. It should be noticed that the maximums of in-degree and out-degree are both larger in Windsor-Sarnia than in Montreal, indicating that inventors in Windsor-Sarnia have a higher degree of mobility. A guess is that there would be less personnel mobility in innovation networks dominated by universities and public institutions.

From the perspective of bonding and connecting, the Windsor-Sarnia region is private-dominated and externally-dominated, while Montreal is more diverse, with a good balance between internal and external, national and international, companies and other institutions. Internal actors of Montreal have a certain influence on the regional innovation networks, such as McGill University, while internal actors of Windsor-Sarnia are not as important as Montreal's.

In terms of correlations between different pairs of roles, several shared features exist in both regions. First, the abilities of bonding and connecting are always highly related. That is to say, if an actor has a great many connections, it will be more likely to have better control over innovation networks. Moreover, if an actor has a high level of bonding and connecting abilities, it will face a higher possibility of personnel mobility. Second, the results of two regions both demonstrate that an outstanding capability of bonding and connecting will not generally contribute to acquiring more external links. Also, based on the correlation analysis, an actor with many internal links will lose their inventors or absorb new inventors less frequently.

4.3. Evolution of Actor's Roles over All Periods

All fifty years are divided into two periods, before 1990 and after. In the first period, two regions are both in an emerging state, with limited engaged actors and collaborative links. In the second period, an increasing number of new actors quickly participate in local innovation networks and bring new distribution patterns of actor's roles. In this section, the patterns of different periods will be investigated and compared. Also, when actors with key roles enter and quit will be answered.

4.3.1 The Montreal Region

4.3.1.1 Period One: from 1970 to 1990

In the first period between 1970 and 1990, the Montreal region faces an increase in the number of companies and public institutions engaged in mobility networks and cooperation networks. The N-I index climbs at the peak during 1976 and 1980, and then slightly come down in the following years. In other words, other international actors gradually participate in Montreal's local innovation network.

Most of the key actors with critical roles do not enter into the Montreal's network during the first period. According to Appendix.1, a company named Merck Sharp & Dohme Corp. shows its importance from multiple perspectives from 1981 to 1985 but disappears after then. Except for Merck Sharp & Dohme Corp., other actors, such as American Home Products Corp, also have a relatively significant influence on the local innovating activities for over five years.

Figure 18 Period One for the Montreal Region

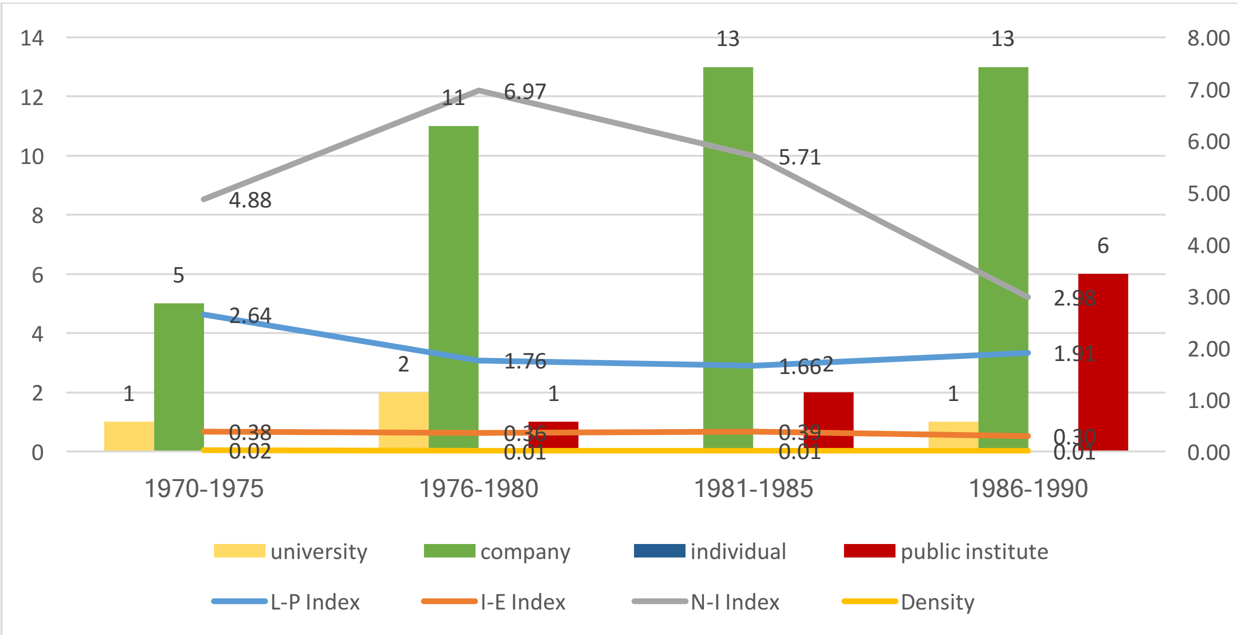
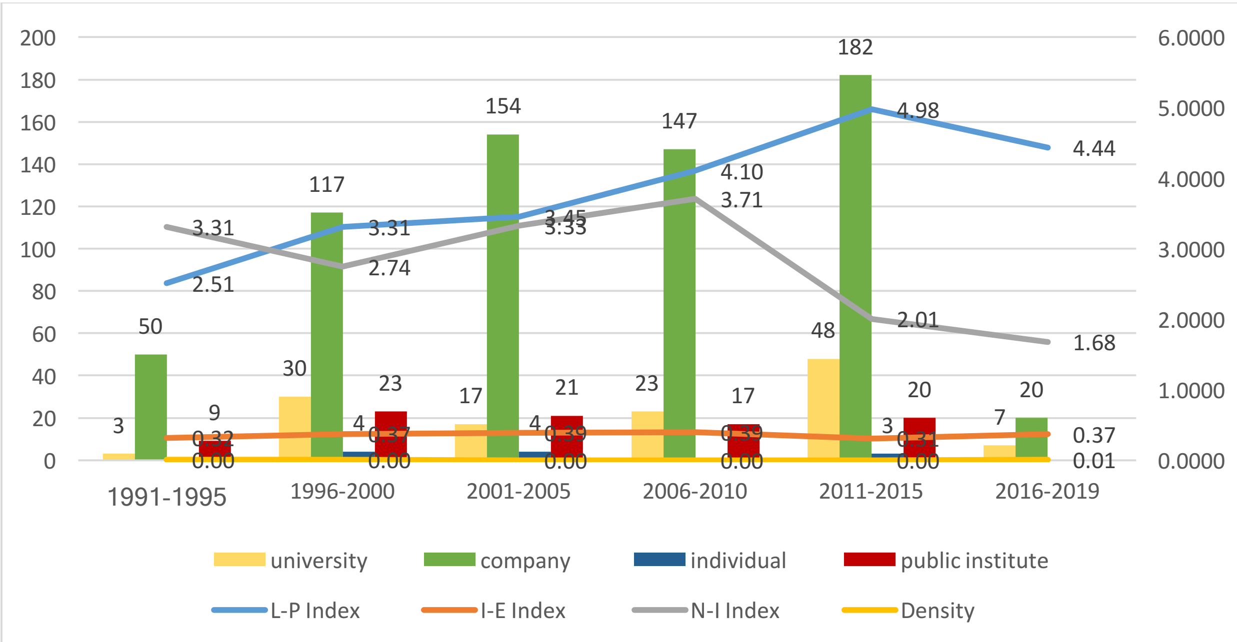


Table 27 The Evolution of Key Actors in the 1st Period (Montreal)				
	1970-1975	1976-1980	1981-1985	1986-1990
top_external	0	0	1	0
top_internal	0	1	1	1
top_out-degree	0	0	1	1
top_in-degree	0	1	2	0
top_bonding	0	0	1	0
top_connecting	0	1	1	0
Calculated by Author.				

4.3.1.2 Period Two: From 1991 to 2019

During the second period, the N-I index keeps declining, indicating the involvement of more international actors, while the I-E still maintains a stable amount between 0.3 and 0.4. In the meanwhile, the L-P index gradually increases from 2 to approximately 5 in the years between 2011 and 2015, indicating around five actors are participating in each patent on average.

Figure 19 Period Two for the Montreal Region



Except for individuals, the other three groups (university, company and public institution) all face rapid growth in the second period. For example, there are fewer than 14 companies at the end of the first period, but this number in the second period increases to more than 180 at a rapid speed. The number of engaged public institutions keeps a stable status of around 20. Universities become less engaged in patenting the chemical industry during 2001 and 2005 but gradually improve again after 2006.

It is obvious to find more identified key actors in the second period in all six dimensions. Key public institutions, such as National Center for Scientific Research and Hydro-Quebec, enter into the local network at the first moment of the second period (from 1990 to 1995), then regularly exist as the crucial actors for over ten years. McGill University becomes a center a little later than these public institutions, entering during the second five years. As an influential actor in the larger scheme of things, Angers University becomes active only between 2005 and 2010.

Like universities, some prominent companies, such as Boehringer Ingelheim and ACEP, enter into Montreal's innovation network after 1995 and constantly occupy a key position for a long time. Companies identified in the first period (1970 – 1990) also make great contributions, such as

Merck and Co. and its sister companies, including Merck Frosst Company and Merck Sharp & Dohme Corp. By comparison, the key actors in Montreal have a strong influence on more extended periods than those in the Windsor-Sarnia region.

Table 28 The Evolution of Key Actors in the 2nd Period (Montreal)

	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2019
top_external	1	5	8	11	7	1
top_internal	0	7	7	8	6	1
top_out-degree	1	2	8	8	8	2
top_in-degree	2	3	6	11	8	3
top_bonding	2	7	10	13	10	2
top_connecting	2	5	9	8	6	0

Calculated by Author.

4.3.2 Windsor-Sarnia Region

4.3.2.1 Period One: from 1970 to 1990

In the Windsor-Sarnia region, the I-E index is relatively high, indicating the local innovation network does not proactively absorb external actors in this period. The N-I index suggests that the majority of actors are coming from other countries (out of Canada). The percentage of international actors increases year by year after 1980. Further, at the end of the first period (1986-1990), the number of companies grows at a rapid rate, from 10 to 32. Other organizations, such as public institutions and universities, do not face vast changes during all 20 years.

Similar to Montreal, the first period of the Windsor-Sarnia region only has very few key actors who are identified in the last section, such as Exxon Research & Engineering Co. Other key actors do not start to enter into the local network yet.

Figure 20 Period One for the Windsor-Sarnia Region

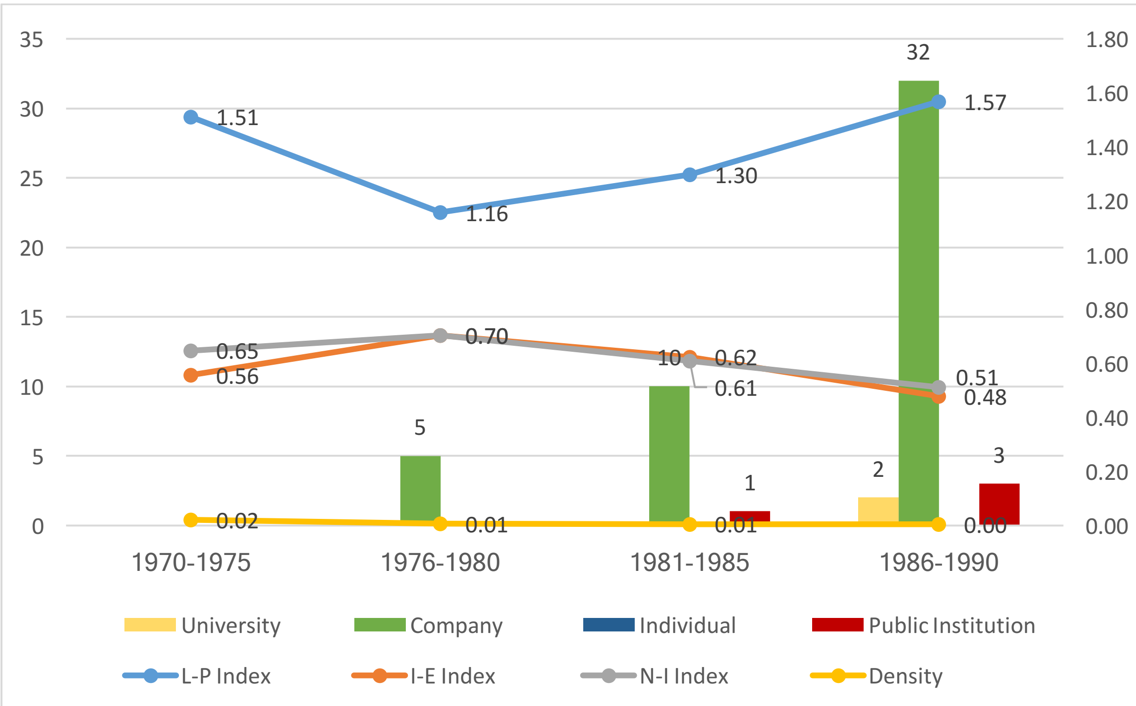


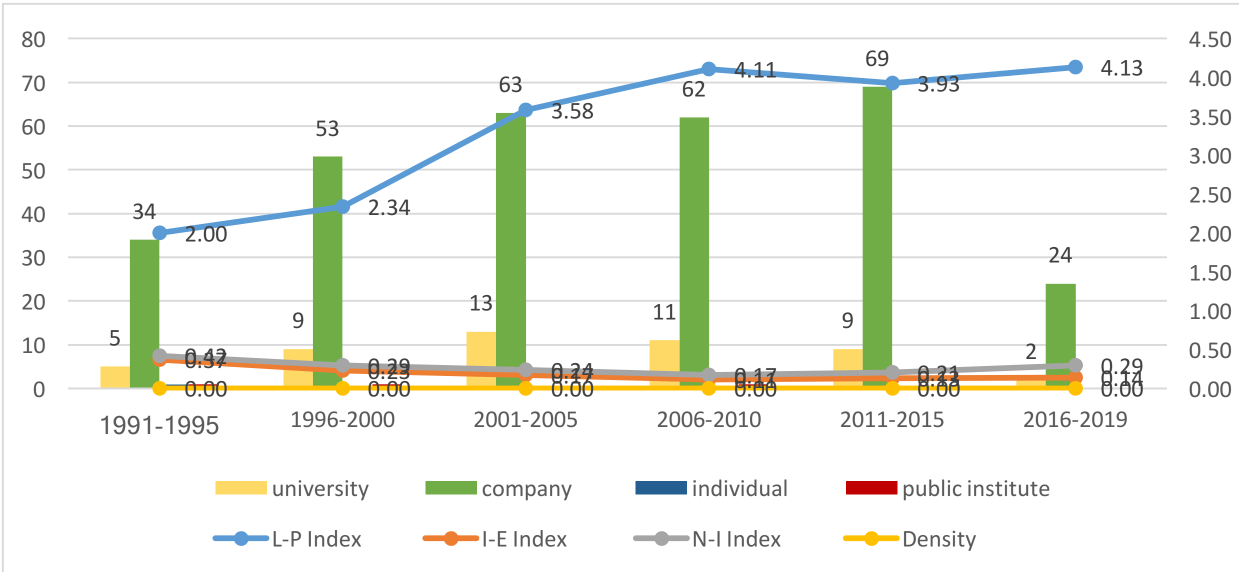
Table 29 The Evolution of Key Actors in the 1st Period (Windsor-Sarnia)

	1970-1975	1976-1980	1981-1985	1986-1990
top_external	0	0	0	1
top_internal	0	0	3	0
top_out-degree	0	1	1	1
top_in-degree	0	1	1	0
top_bonding	0	1	1	0
top_connecting	0	1	1	0

Calculated by Author.

4.3.2.2 Period Two: From 1991 to 2019

Figure 21 Period Two for the Windsor-Sarnia Region



In the second period, the number of companies increases from 34 in the first five years to 69 in the second-last five years. However, the absolute number of companies in the Windsor-Sarnia region is lower than that of Montreal, which has a peak value of around 180. After entering into the second period, public institutions almost disappear from the Windsor-Sarnia's innovation networks.

Besides, the L-P index increases from 1.99 to 4.13, mainly exceeding the degree of the first period. However, the N-I index and the I-E index gradually become smaller, meaning that more and more international actors are introduced, constituting an internationalized innovation region.

At the beginning of the second period, most of the identified key actors still do not enter into the networks yet. This situation starts to change after 1995. However, the identified key actors always keep active in the local network for less than 15 years. For example, E. R. Squibb & Sons, Inc., as a company with great influences on the overall network, disappears from the regional network after 2000. Then a lot of new companies enter into the network, acting as new key actors, such as Lanxess Inc. and Wyeth. In general, the average duration for key actors to exist in local networks is generally shorter in Windsor-Sarnia than in Montreal.

Table 30 The Evolution of Key Actors in the 2nd Period (Windsor-Sarnia)						
	1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2019
top_external	0	4	6	8	5	1
top_internal	0	0	2	4	3	3
top_out-degree	4	6	10	6	2	0
top_in-degree	2	5	7	11	6	2
top_bonding	3	5	8	8	5	1
top_connecting	2	4	9	7	4	1
Calculated by Author.						

4.3.3 Comparison

There are significant differences in the evolution of innovation networks between the Montreal region and the Windsor-Sarnia region. Montreal's networks are centred around universities and public institutions, while Windsor-Sarnia is more private-oriented. In Montreal, the number of universities and public institutions remains a stable level after the first period, and there is a rapidly increasing number of companies. However, for the Windsor-Sarnia region, public institutions and universities almost do not play any role during the second period. With a similar level of the internally-external index and the proportion of links and patents, Montreal and Windsor-Sarnia have a distinct National-International Index. For Montreal, the N-I index is around 2.5 with a declining trend. However, for Windsor-Sarnia, this index is always under 0.5, indicating that Windsor-Sarnia has many fewer national actors than Montreal. In other words, the percentage of international actors is much greater in Winsor-Sarnia.

According to Table 31, there is an apparent distinction between the existing years of key actors in Montreal and in Windsor-Sarnia, namely that key actors in Montreal stay within network longer than in Windsor-Sarnia. In Montreal, three key actors play an essential role for over 20 years, while in Windsor-Sarnia, there are no such actors. Only around 10 percent of key actors are active as key actors for over ten years in Windsor-Sarnia. Nevertheless, for Montreal, 30 percent of total key actors participate in the local network for more than ten years. To conclude, Montreal's innovation network is more stable and diverse than that of Windsor-Sarnia.

Table 31 Years of Existing as Key Actors				
	Montreal (n=50)		Windsor-Sarnia (n=47)	
	Count	Percent	Count	Percent
0-5 years	25	50.00%	24	51.06%
6-10 years	10	20.00%	18	38.30%
11-15 years	6	12.00%	4	8.51%
16-20 years	6	12.00%	1	2.13%
21-25 years	2	4.00%	0	0.00%
26-30 years	1	2.00%	0	0.00%
Calculated by author.				

Also, we conduct a correlation analysis between the existing years as key actors and other variables (results are shown in Table 32). It can find that, in the public-oriented network, the identifications of actors (universities, public institutions or companies) are not highly related to the years of existing. However, other variables (such as if_bonding, if_external and if_in-degree) have a significant relationship. In other words, if an actor in Montreal has more external collaborative partners, more inward knowledge flows and more partners, it will have a larger possibility to exist in collaborative innovation networks for longer periods. In Windsor-Sarnia, the only significant variable is whether an actor is a public-institution. In other words, if an actor is a public institution, it is more likely to disappear from the local network within the short term. Therefore, different orientations of networks lead to different patterns of stability and persistence.

Table 32 Correlations between Years of Existing as Key Actors and Other Variables				
Variables	Montreal (n=50)		Windsor-Sarnia (n=47)	
	r	p	r	p
If bonding	0.36**	0.011	0.12	0.412
If connecting	0.10	0.477	0.01	0.924
If internal	0.06	0.668	-0.04	0.776
If external	0.34**	0.016	0.17	0.249
If in-degree	0.30**	0.034	0.04	0.798
If out-degree	0.23	0.105	0.01	0.924
If university	-0.04	0.777	0.15	0.315
If company	-0.13	0.386	0.12	0.413
If public institution	0.19	0.189	-0.29*	0.050
a=0.05**; a=0.1*; spearman analysis Calculated by author.				

5. Discussion

According to our current results, we draw some conclusions. We produce our results based on the sample data from the chemical industry in two Canadian regions, which show relatively unique distribution patterns of actors' roles. First, the patterns of actors' roles are different in the two regions. Montreal's network is a public-dominated network; it has a great number of universities, public institutions and companies, with the feature that local actors absorb knowledge from both internal and external resources. Prior research has shown that in the chemical industry, universities and R&D institutions contribute more than companies since the training of scientists and engineers and obtaining experimental techniques are two essential resources of knowledge the chemical industry. However, in Windsor-Sarnia, the private-dominated network is mainly composed of companies, acquiring external knowledge and employing it in their local innovation activities. These two orientations lead to distinctions of patenting behaviours in innovation networks.

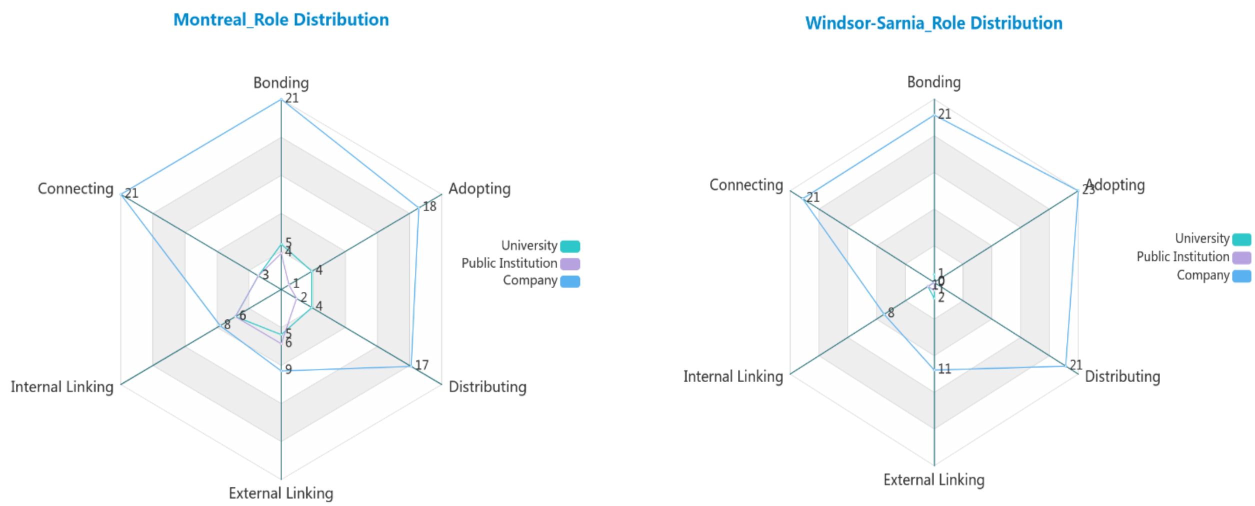
Public-private partnerships have been widely discussed in previous papers, showing a moderating and stimulating effect on the process of innovation collaborations (Azagra-Caro and Consoli, 2016). Private organizations have less willingness to transfer their knowledge to other companies who are their potential competitors. Unlike private organizations, public organizations are more disposed to spread out knowledge to the public (Broekel and Boschma, 2011). The results of actors' distribution in Montreal support these previous conclusions by showing a more significant number of patents, participated actors, collaborative links and L-P index. There are also collaborative relationships between universities and companies, companies and public institutions, and universities and public institutions.

In Windsor-Sarnia, companies are the dominating actors, with fewer collaborative relationships and a smaller number of patents per company. Although the total number of patents is much larger, the actors in Windsor-Sarnia are more willing to innovate and patent in a smaller group with fewer collaborative partners. Companies tend to innovate independently, especially when few public partners are involved. The distribution of actors in Windsor-Sarnia is consistent with the standpoint that firms are less willing to collaborate with their competitors. Most of the collaborative relationships between companies are implemented through personnel mobility rather than direct cooperation, especially in the field of biochemistry and pharmaceutical chemistry.

Additionally, the network of Windsor-Sarnia, as a private-dominated type, has a large percentage of collaborative partners coming from different regions, indicating relationship networks across geographical boundaries. Moreover, this percentage is rapidly increasing year by year. These results suggest that geography does not generally have a significant influence on establishing relationships between actors in innovation networks. According to Grillitsch (2015), the location of companies shows a weak relationship with their innovativeness. As introduced in the literature review, other factors (such as cognitive, social and organizational proximity) are considered more important. Kuttim (2016) discovers that social proximity and cognitive proximity are more critical than geographical proximity in international cooperation. Winsor-Sarnia, as a private-dominated and externally-oriented region, indeed tends to collaborate more with some specific groups of actors, for example, actors from the United States and Australia. It should be noticed that some actors that frequently collaborate with Windsor-Sarnia actors are located in Detroit, which is an American city nearby Windsor. It is hard to conclude whether high-frequent relationships are impacted by geographical proximity or cognitive proximity if only based on our current data. The Montreal network suggests a potential impact of other types of proximities on innovation activities. For instance, a great number of collaborative actors are located in Paris (France), which is also a predominantly francophone area like Montreal. Boschma (2005) points out that common languages and shared habits, which are a part of informal institutional proximity, provide a basis for economic coordination and interactive learning. The patenting pattern of Montreal observed in this study provide additional evidence for this point. Therefore, geography may be not the first-order effect of becoming important in many innovation activities. In this case, further studies are required.

In Windsor-Sarnia, the percentages of universities (8.73% for mobility network and 19.59% for cooperation network) are similar to those in Montreal (11.40% and 22.45). However, universities in Windsor-Sarnia do not play a vital position in the network. Two possible reasons are proposed based on the current results. 1) Fritsch (2001) points out that spatial closeness is especially critical for collaborations between public organizations and private organizations. Most of the involved universities in Windsor-Sarnia are external actors. Windsor-Sarnia has few internal actors in the mobility network (10.91%) and the cooperation network (4.12%), while Montreal has 31.29% and 19.73%, respectively. In other words, local universities may play a more critical role than external universities in the process of knowledge transfer. 2) The significant difference between the two regions occurs in the percent of public institutions. Public institutions may provide a moderating function between universities and companies. Future studies may shed additional insights on this matter.

Figure 22 Overview of Roles' Distribution in Two Regions from Six Perspectives



Drawn by author.

In this thesis, three pairs of functional roles are considered as major indicators to measure the importance of actors, i.e. bonding or connecting, communicating with internal actors or external actors, and distributing or absorbing knowledge. According to our results, key actors of both regions are identified and compared. Figure 23 provides a more straightforward picture to show the different distributions of actors' roles in two regions. In both private-oriented networks and public-oriented networks, companies are always the dominant group of innovators. However, different orientations also lead to distinctive patterns of roles' distributions from six perspectives. In the public-oriented network, universities and public institutions have similar performances in all dimensions. It should be noticed that, in the dimensions of collaborating with internal or external actors, universities and public institutions almost achieve a similar level of performance as companies. However, in the private-dominated network, there are very few universities and institutions playing essential roles in their regional innovation network.

Furthermore, the different types of roles are interrelated. First, the ability of bonding is highly associated with connecting. According to Schilling and Phelps (2007), the capability of information transmission is highly associated with the degree of gathering collaborative partners. A high level of bonding capability will ensure that information can transfer within a short distance (both spatial and non-spatial). Also, based on the principle of "preferential attachment", innovation actors prefer to collaborate with others who establish many collaborative relationships and possess abundant resources within and outside networks (Goetze, 2010). In short, if an organization establishes many collaborative connections, it will be more likely to have a higher level of betweenness centrality, which means better control over the innovation network. Also, if an actor has a high level of bonding and connecting ability, it will face a higher possibility of personal mobility. However, the ability of bonding and connecting is not generally related to a better capability of communicating with external partners. Lastly, based on the correlation analysis for both regions, an actor with many internal relations will face a lower possibility of personnel mobility. One possible explanation is that such actors tend to collaborate with internal partners rather than external ones. Cooperating with internal partners can provide the necessary knowledge that they require in their innovation activities so that they have few demands for personal mobility.

Lastly, the existing years of being key actors indicate distinctive patterns in the two regions. Holbrook and Wolfe (2005) suggest that there are three waves of regional development of innovation networks in Canada from the 1960s to the present. From the 1970s, Canadian regions started to build up research infrastructure, upgrade training and education systems, and develop supporting systems of finance and knowledge transfer. After the 1990s, regional policies in Canada paid more attention to innovation collaborations, balancing the R&D resources and recruits between public and non-public sectors (Holbrook and Wolfe, 2005). The similar waves appear in our current analysis results. In the beginning, the innovation networks in both regions (Windsor-Sarnia and Montreal) had a smaller number of participating actors. Few actors chose to enter into the local chemical field during the period between 1970 and 1990. However, the number of actors rapidly increased after 2000 in both regions.

According to our results, the public-dominated network is relatively stable. After the second period, a great number of key actors play their core roles for over ten years in Montreal. Some top-ranked actors, such as Hydro Quebec, are very active in the first five years and exit in the following years. In Montreal, actors who frequently communicate with external partners tend to be successful for a more extended period. However, in Windsor-Sarnia, the speed of replacing key actors is much quicker. Very few key actors exist in the local networks of Windsor-Sarnia for over ten years. Unlike Montreal, Windsor-Sarnia, as a private-oriented region, does not show any apparent relationships between existing years and other variables except for being a public institution. If an actor is a public institution, it will disappear more quickly than others in Windsor-Sarnia. In this case, our results show weak support for the "time" principle of networking development. Hence, different orientations show different patterns again in the dimension of the existing years of being key actors.

6. Limitation and Future Direction

Some limitations exist in this thesis. First, patent data have inherent limitations, which have been mentioned in the data section. Patents provide empirical data that permit describing collaborative relationships, identify actors' roles, and analyze their distribution and evolution over fifty years. However, if we intend to analyze further, we need additional quantitative data. For example, according to our current results, it is hard to convincingly conclude which type of proximity has a significant influence on innovation activities within innovation networks. Also, patent data lack the information about the organizations of each inventor, probably bringing about an issue of underestimating the activities of assignees from the networking perspective. In this case, more quantitative and qualitative data should be included in future studies.

Finally, we only select two Canadian regions as the cases for this thesis, showing the different patterns of actors' roles within innovation networks. However, different industries and regions may have different patterns of roles. If possible, future studies can include more data from other industries, regions or countries, in order to compare whether there are any similarities and differences based on different geographical boundaries.

7. Conclusion

Through collaborative innovation, diverse types of relationships are established among different entities, such as universities, public institutions, individuals and companies, in different circumstances of geography, culture and society. Different entities play distinct roles in collaborative innovations. In this thesis, three pairs of functions are summarized and used to assign innovative entities as different roles, i.e. exchanging knowledge with internal or external actors, distributing or adopting knowledge, and bonding or connecting with other networked actors. The chemical industry and two Canadian regions are selected as cases and we analyze the corresponding patent data from the perspective of distribution and evolution. Montreal, with a public-dominated network, shows a more complex distribution of roles, while Windsor-Sarnia, with a private domination, indicates a simple pattern. Based on our current results from the fifty-year data, Montreal has a relatively stable evolution, with key actors being active for more years. As for Windsor-Sarnia, key actors experience a higher level of personnel mobility.

Through answering the question of how actors' roles are distributed and evolving in regional co-patent networks, this thesis investigates the distributing patterns of actors' roles in two regions. At the theoretical level, we proposed a new categorization of actors' roles. The framework of six dimensions provides a systematic aggregation of actor's functions from previous papers. At the practical level, this thesis uses social network analysis to investigate new cases and finds different patterns of innovation networks with different orientations. Our current results are mostly exploratory and descriptive, answering the question of "how" and "who". In the future, more studies should follow up to explain why such patterns exist and whether they can be found in a broader region or country.

Appendix

Appendix.1 Roles' Evolution in Montreal Region

1.1 Period.1

Period.1 in Windsor-Sarnia Region			
	Label	City	Period
connecting	Canadian Industries Limited	Montreal	1_2
	Merck Sharp & Dohme Corp.	Rahway	1_3
bonding	Merck Sharp & Dohme Corp.	Rahway	1_3
external	Merck Sharp & Dohme Corp.	Rahway	1_3
internal	Canadian Industries Limited	Montreal	1_2
	Societe Nationale Elf Aquitaine	Courbevoie	1_3, 1_4
out-degree	Merck Sharp & Dohme Corp.	Rahway	1_3
	Bio-Mega Inc.	Laval	1_4
in-degree	American Home Products Corp.	New York	1_2, 1_3
	Merck Sharp & Dohme Corp.	Rahway	1_3

1.2 Period.2

Period.2 in Montreal Region			
	Label	City	Period
Connecting	Alcan International Limited	Montreal	2_1
	AstraZeneca A.B.	Sodertalje	2_4
	Bio-Chem Pharma Inc.	Laval	2_3
	Boehringer Ingelheim	Burlington	2_1, 2_2, 2_3, 2_4
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5

	Gemin X Biotechnologies	Montreal	2_3
	Hospital Sainte-Justine	Montreal	2_2, 2_3, 2_5
	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6
	Institut National de Recherche Scientifique	Montreal	2_3
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5
	Merck Frosst Company	Rahway	2_1, 2_2, 2_3, 2_4, 2_5
	Merck Sharp & Dohme Corp.	Rahway	2_4, 2_5
	National Research Council of Canada	Toronto	2_5
	TaiMed Biologics, Inc.	Taipei	2_4
	Theratechnologies Inc.	Saint Laurent	2_2, 2_3, 2_4, 2_5
	Angers University	Angers	2_4
	Valorisation-Recherche L.P.	Montreal	2_3
	Vertex Pharmaceuticals	Boston	2_4, 2_5
bonding	ACEP Inc.	Montreal	2_2, 2_3, 2_4, 2_5
	Alcan International Limited	Montreal	2_1
	AstraZeneca A.B.	Sodertalje	2_4
	Bio-Chem Pharma Inc.	Laval	2_3
	Boehringer Ingelheim International GmbH	Ingelheim am Rhein	2_3, 2_4, 2_5
	Boehringer Ingelheim	Burlington	2_1, 2_2, 2_3, 2_4
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5
	Gemin X Biotechnologies	Montreal	2_3

	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6
	Institut National de la Sante et de la Recherche Medicale	Paris	2_2, 2_4
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5
	Merck Frosst Company	Rahway	2_1, 2_2, 2_3, 2_4, 2_5
	Merck Sharp & Dohme Corp.	Rahway	2_4, 2_5
	National Research Council of Canada	Toronto	2_5
	RSEM, Limited Partnership	Montreal	2_4, 2_5
	TaiMed Biologics, Inc.	Taipei	2_4
	The Hong Kong Polytechnic University	Kowloon	2_3, 2_4, 2_5, 2_6
	The Regents of the University of California	Oakland	2_2, 2_5, 2_6
	Theratechnologies Inc.	Saint Laurent	2_2, 2_3, 2_4, 2_5
	Angers University	Angers	2_4
	Valorisation-Recherche L.P.	Montreal	2_3
	Vertex Pharmaceuticals	Boston	2_4, 2_5
external	ACEP Inc.	Montreal	2_2, 2_3, 2_4, 2_5
	Adaerata Limited Partnership	Montreal	2_4
	Alcan International Limited	Montreal	2_1
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5
	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6

	Institut National de la Sante et de la Recherche Medicale	Paris	2_2, 2_4
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5
	Merck Frosst Company	Rahway	2_1, 2_2, 2_3, 2_4, 2_5
	Merck Sharp & Dohme Corp.	Rahway	2_4, 2_5
	Phos-tech Lithium Inc.	Montarville	2_4, 2_5
	The Hong Kong Polytechnic University	Kowloon	2_3, 2_4, 2_5, 2_6
	The Sir Mortimer B.	Montreal	2_2, 2_3, 2_4, 2_5
	Universita Degli Studi di Milano	Montreal	2_4
	Angers University	Angers	2_4
	University of South Florida	Tampa	2_3, 2_4, 2_5
	Valorbec S.E.C.	Montreal	2_3
	Valorisation-Recherche L.P.	Montreal	2_3
internal	ACEP Inc.	Montreal	2_2, 2_3, 2_4, 2_5
	Adaerata Limited Partnership	Montreal	2_4
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5
	Hong Kong Polytechnic University	Hong Kong	2_5
	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6
	Institut National de la Sante et de la Recherche Medicale	Paris	2_2, 2_4
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5

	RSEM, Limited Partnership	Montreal	2_4, 2_5
	Schering Corporation	Kenilworth	2_4
	The Regents of the University of California	Oakland	2_2, 2_5, 2_6
	The Sir Mortimer B.	Montreal	2_2, 2_3, 2_4, 2_5
	Angers University	Angers	2_4
	Universite Louis Pasteur	Paris	2_2
	University of Vermont and State Agricultural College	Burlington	2_3
	Valorbec S.E.C.	Montreal	2_3
	Valorisation-Recherche, Societe en Commandite	Montreal	2_3
out-degree	BHI Limited Partnership	Laval	2_4, 2_5
	Bio-Chem Pharma Inc.	Laval	2_3
	Bio-Mega Inc.	Laval	2_1
	Boehringer Ingelheim International GmbH	Ingelheim am Rhein	2_3, 2_4, 2_5
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5
	ConjuChem Inc.	Montreal	2_3
	DANA-FARBER CANCER INSTITUTE, INC.	Boston	2_5
	Gilead Sciences, Inc.	Foster City	2_4, 2_5
	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5
	Merck Frosst Company	Rahway	2_1, 2_2, 2_3, 2_4, 2_5
	Merck Sharp & Dohme Corp.	Rahway	2_4, 2_5
	National Research Council of Canada	Ottawa	2_5
	The Hong Kong Polytechnic University	Hung Home	2_3, 2_4,

			2_5, 2_6
	The Royal Institute for the Advancement of Learning	Montreal	2_4, 2_5, 2_6
	Angers University	Angers	2_4
	Valorisation-Recherche L.P.	Montreal	2_3
	Viro Chem Pharma, Inc.	Montreal	2_3
in-degree	AstraZeneca A.B.	Sodertalje	2_4
	Bio-Mega Boehringer Ingelheim Research Inc.	Laval	2_1
	Boehringer Ingelheim International GmbH	Ingelheim am Rhein	2_3, 2_4, 2_5
	Boehringer Ingelheim	Burlington	2_1, 2_2, 2_3, 2_4
	Centre National de la Rechecch Scientifique	Paris	2_1, 2_2, 2_3, 2_4, 2_5
	Conjuchem Biotechnologies Inc.	Montreal	2_3, 2_4
	Forum Pharmaceuticals, Inc.	Waltham	2_5
	Hydro-Quebec	Montreal	2_1, 2_2, 2_3, 2_4, 2_5, 2_6
	McGill University	Montreal	2_2, 2_3, 2_4, 2_5
	Merck Frosst Company	Rahway	2_1, 2_2, 2_3, 2_4, 2_5
	Merck Sharp & Dohme Corp.	Rahway	2_4, 2_5
	National Research Council of Canada	Ottawa	2_5
	PROMETIC PHARMA SMT LIMITED	Cambridge	2_5
	Syros Pharmaceuticals, Inc.	Cambridge	2_6
	The Hong Kong Polytechnic University	Hong Kong	2_3, 2_4, 2_5, 2_6
	The Royal Institute for the Advancement of Learning	Montreal	2_4, 2_5, 2_6

	Angers University	Angers	2_4
	University of Montreal	Montreal	2_4
	Vertex Pharmaceuticals	Boston	2_4, 2_5

Appendix.2 Roles' Evolution in Windsor-Sarnia Region

2.1 Period.1

Period.1 in Windsor-Sarnia Region			
	Label	City	Period
connecting	Exxon Research & Engineering Co.	Annandale	1_2, 1_3
bonding	Exxon Research & Engineering Co.	Annandale	1_2, 1_3
external	Wayne State University	Detroit	1_4
internal	Commonwealth Scientific	Canberra	1_3
	Industrial Research Organization	Melbourne	1_3
	The Broken Hill Proprietary Company Limited	New South Wales	1_3
out-degree	Exxon Research & Engineering Co.	Annandale	1_2, 1_3
in-degree	Exxon Research & Engineering Co.	Annandale	1_2, 1_3

2.2 Period.2

Period.2 in Windsor-Sarnia Region			
	Label	City	Period
connecting	American Home Products Corp.	New York	2_3
	BASF Corporation	Florham Park	2_4, 2_5
	Bayer Aktiengesellschaft	Leverkusen	2_1, 2_3
	Bayer Inc.	Sarnia	2_2, 2_3
	Bristol-Meyers Squibb Company	Princeton	2_4, 2_6
	Exxon Research & Engineering Co.	Annandale	2_1
	FMC Corporation	Philadelphia	2_3, 2_4
	International Fuel Cells	Windsor	2_2
	Lanxess Inc.	Sarnia	2_3, 2_4, 2_5
	Merck Sharp & Dohme	Rahway	2_4
	Pharmacopeia Drug Discovery, Inc.	Princeton	2_3

	Pharmacopeia Inc.	San Diego	2_5
	Rhodia Chimie	Billancourt Cedex	2_3
	Rhodia Inc.	Cranbury	2_4
	Scheeing Corporation	Kenilworth	2_5
	United Technologies Corp.	Hartford	2_2
	UTC Fuel Cells, LLC	Windsor	2_2, 2_3
	Wyeth	Madison	2_3, 2_4
bonding	American Home Products Corp.	New York	2_3
	BASF Corporation	Florham Park	2_4, 2_5
	Bayer Aktiengesellschaft	Leverkusen	2_1, 2_3
	Bayer Inc.	Sarnia	2_2, 2_3
	Bristol-Meyers Squibb Company	Princeton	2_4, 2_6
	Exxon Research & Engineering Co.	Annandale	2_1
	FMC Corporation	Philadelphia	2_3, 2_4
	International Fuel Cells	Windsor	2_2
	LANXESS Deutschland GmbH	Leverkusen	2_4, 2_5
	Lanxess Inc.	Sarnia	2_3, 2_4, 2_5
	Merck Sharp & Dohme	Rahway	2_4
	Pharmacopeia Drug Discovery, Inc.	Princeton	2_3
	Pharmacopeia Inc.	San Diego	2_5
	Sanofi	Princeton	2_4
	Scheeing Corporation	Kenilworth	2_5
	The University of Western Ontario	London	2_1, 2_2
	United Technologies Corp.	Hartford	2_2
	UTC Fuel Cells, LLC	Windsor	2_2, 2_3
	Wyeth	Madison	2_3, 2_4
external	Bayer Inc.	Sarnia	2_2, 2_3
	Bristol-Meyers Squibb Company	Princeton	2_4, 2_6
	Dendreon Corporation	Seattle	2_3, 2_4, 2_5
	LANXESS Deutschland GmbH	Leverkusen	2_4, 2_5

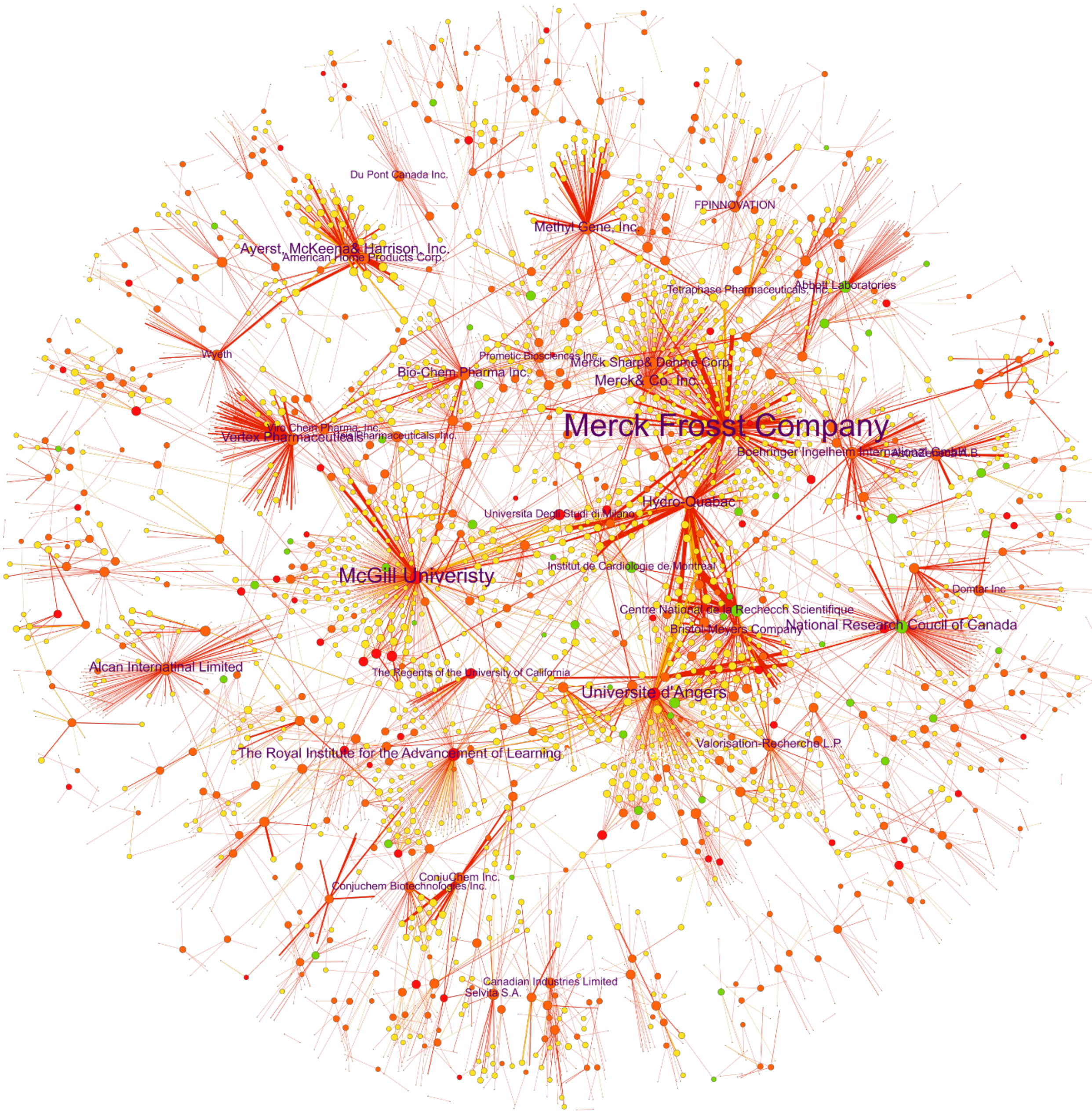
	Lanxess Inc.	Sarnia	2_3, 2_4, 2_5
	Merck Sharp & Dohme	Oss	2_4
	Nova Chemicals	International	2_2, 2_3, 2_4
	Pharmacopeia Drug Discovery, Inc.	Cranbury	2_3
	Pharmacopeia Inc.	La Jolla	2_5
	Sanofi	Paris	2_4
	Scheeing Corporation	Kenilworth	2_5
	The Institute For Chemical Science and Technology	Sarnia	2_2
	Wayne State University	Detroit	2_2, 2_3, 2_4
internal	Bristol-Meyers Squibb Company	Princeton	2_4, 2_6
	Colorado State University Research Foundation	Fort Collins	2_5
	DynamOx, Inc.	Irvine	2_3, 2_4
	Pharmaceuticals, Ltd.	Changshu	2_5, 2_6
	Sanofi	Paris	2_4
	ScinoPharm	Changshu	2_5, 2_6
	TherOx, Inc.	Irvine	2_3, 2_4
out-degree	Bayer Aktiengesellschaft	Leverkusen	2_1, 2_3
	Bayer CropScience AG	Monheim	2_3
	Bayer Inc.	Sarnia	2_2, 2_3
	E. R. Squibb & Sons, Inc.	Princeton	2_1, 2_2
	Exxon Research & Engineering Co.	Florham Park	2_1
	International Fuel Cells	Windsor	2_2
	JDS Uniphase Corporation	Milpitas	2_3, 2_4
	Lanxess Inc.	Sarnia	2_3, 2_4, 2_5
	Lexicon Pharmaceuticals	New Brunswick	2_3
	Merck Sharp & Dohme	Oss	2_4
	Pharmacopeia Drug Discovery, Inc.	Cranbury	2_3
	Rhodia Inc.	Cranbury	2_4
	Scheeing Corporation	Kenilworth	2_5
	The Carborundum Company	Niagara Falls	2_1, 2_2
	United Technologies Corp.	Hartford	2_2

	UTC Fuel Cells, LLC	Windsor	2_2, 2_3
	Wyeth	Madison	2_3, 2_4
in-degree	ARLANXEO Deutschland GmbH	Dormagen	2_5
	BASF Corporation	Florham Park	2_4, 2_5
	Bayer Inc.	Sarnia	2_2, 2_3
	Bristol-Meyers Squibb Company	Princeton	2_4, 2_6
	Dendreon Corporation	San Diego	2_3, 2_4, 2_5
	Exxon Chemical Patents Inc.	Houston	2_1
	Exxon Research & Engineering Co.	Florham Park	2_1
	FMC Corporation	Philadelphia	2_3, 2_4
	International Business Machines Corporation	Armonk	2_1, 2_2
	LANXESS Deutschland GmbH	Cologne	2_4, 2_5
	Lanxess Inc.	Sarnia	2_3, 2_4, 2_5
	Merck Sharp & Dohme	Rahway	2_4
	MSD R&D	Beijing	2_6
	Pharmacopeia Drug Discovery, Inc.	Cranbury	2_3
	Reckitt & Colman Inc.	Wayne	2_2
	Rhodia Operations	Ambervilliers	2_4
	Sanofi	Princeton	2_4
	Scheeing Corporation	Kenilworth	2_5
	Schering Plough Corporation	Kenilworth	2_4
	United Technologies Corp.	Hartford	2_2
	UTC Fuel Cells, LLC	Windsor	2_2, 2_3
	UTC Power Corporation	Windsor	2_3, 2_4

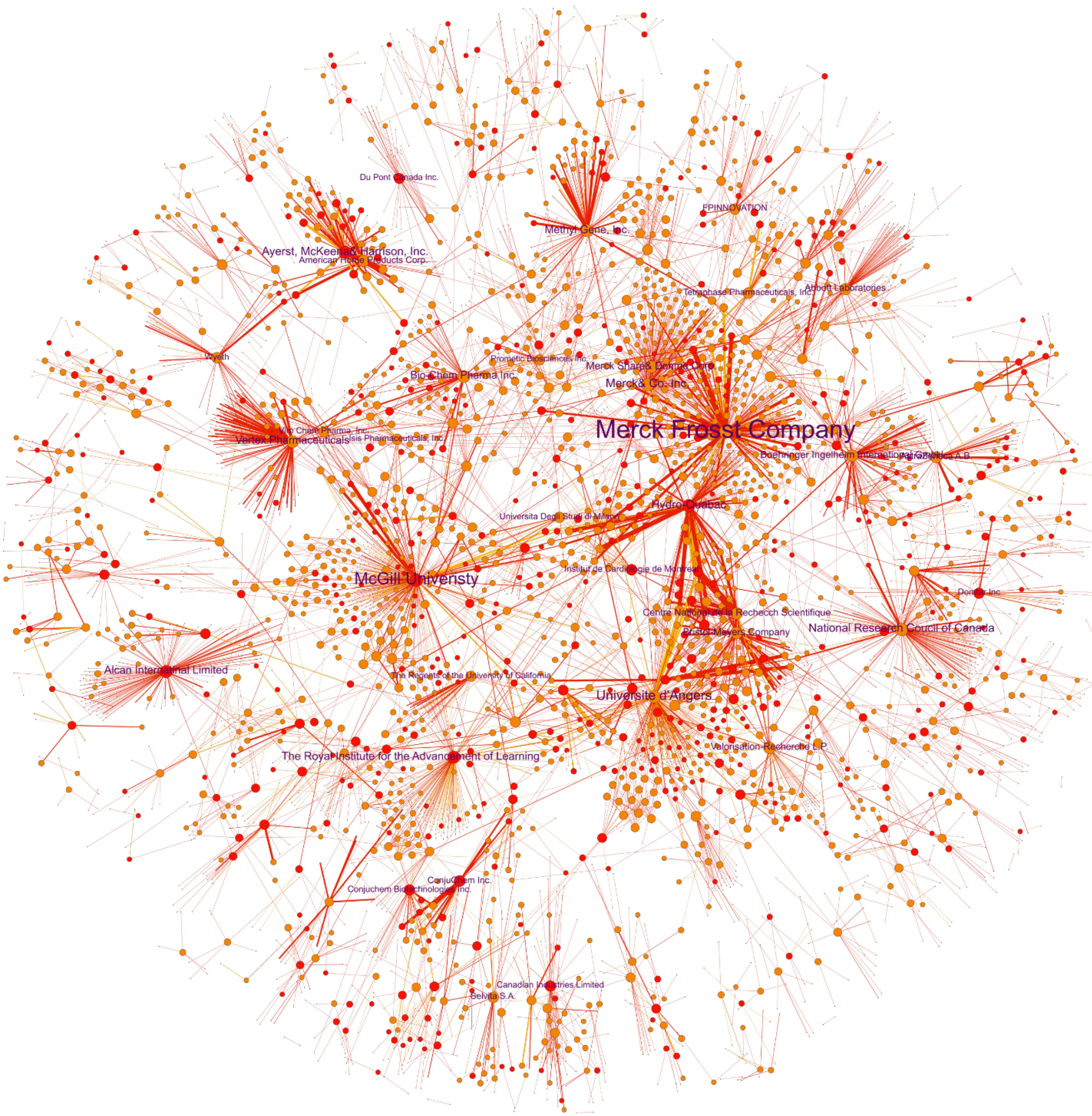
Appendix.3 Networks for the Montreal Region

3.1 Overall Network

3.1.1 Based on Types of Actors

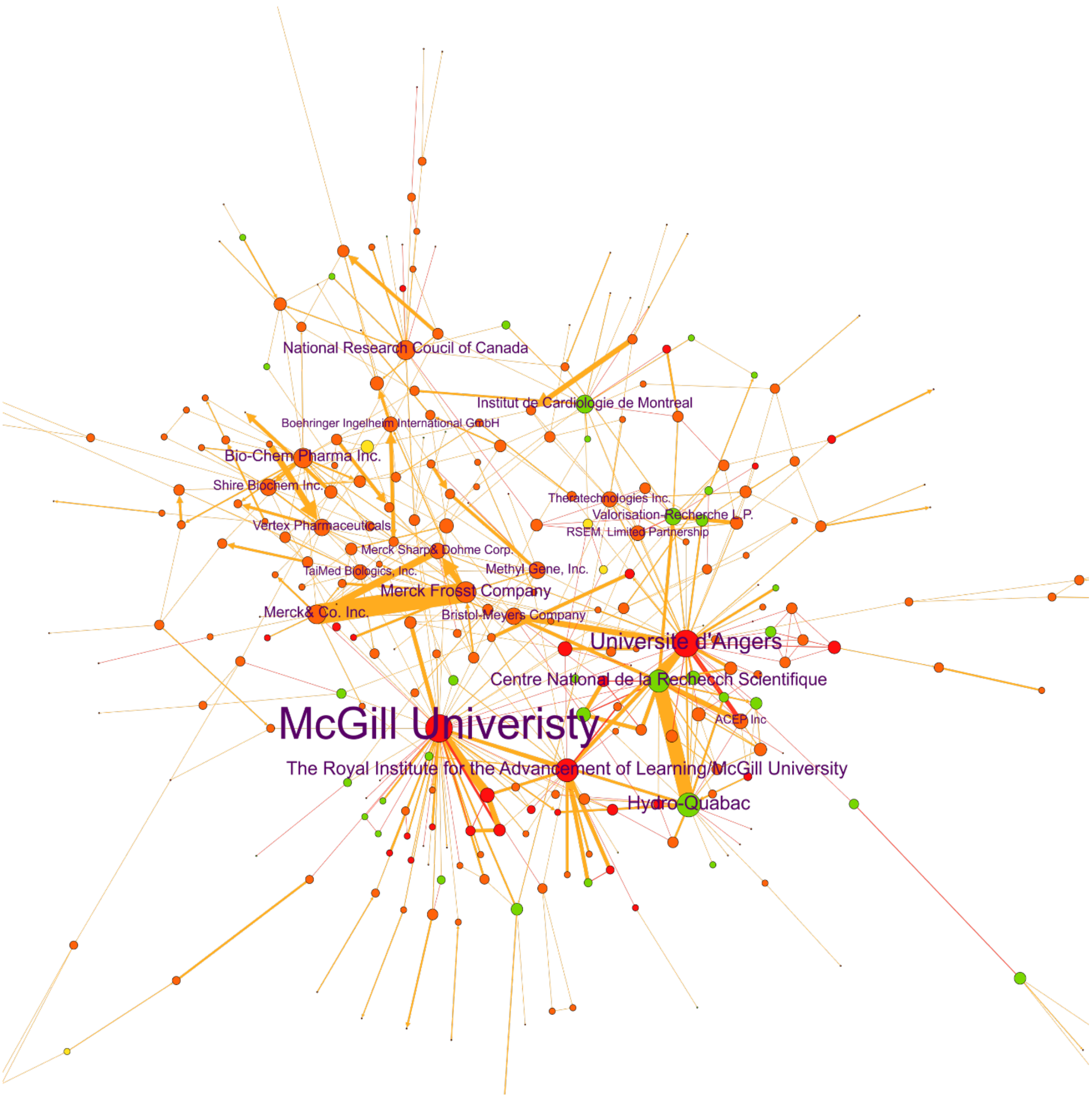


3.1.2 Based on Regions

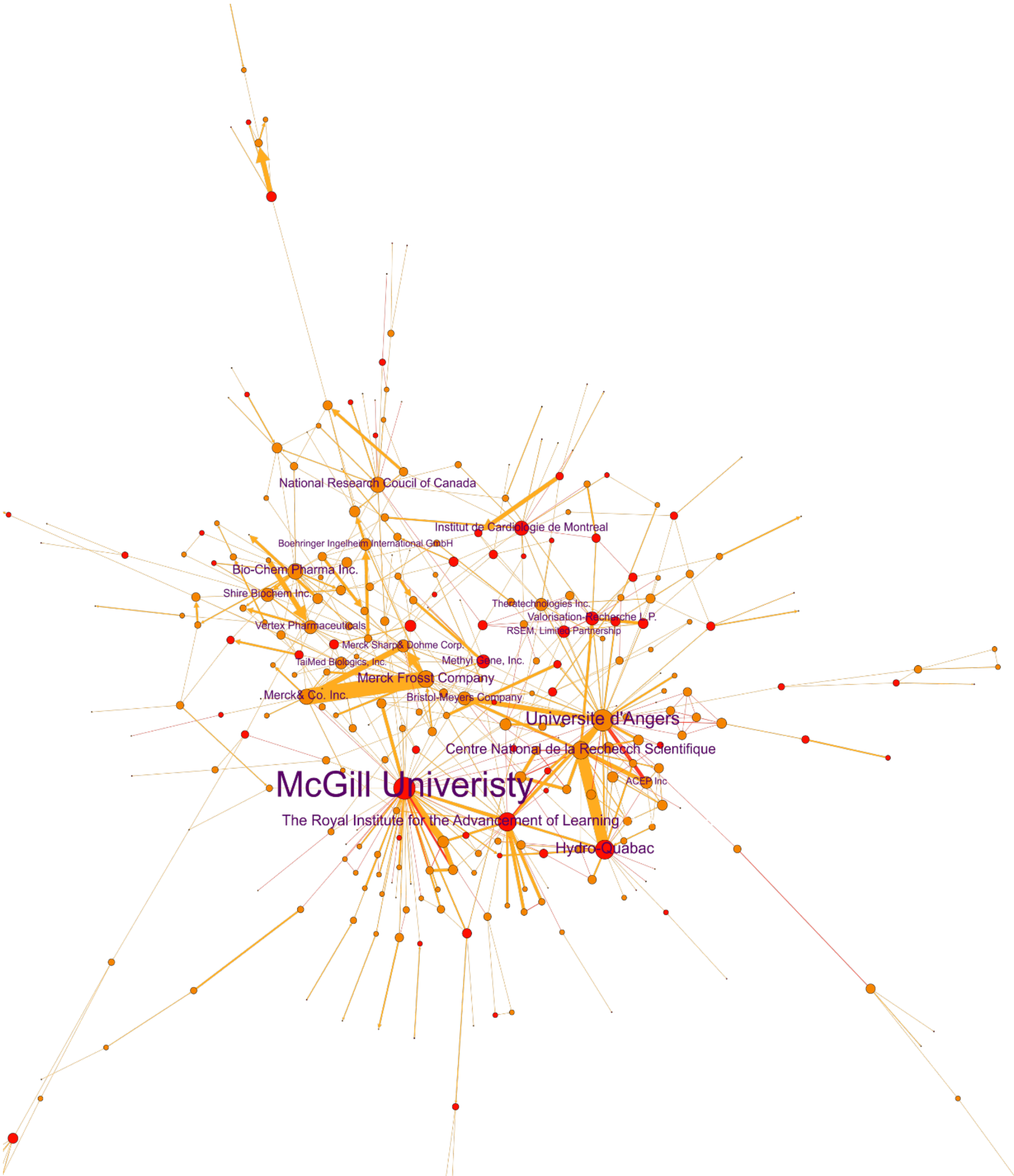


3.2 Mobility Network & Cooperation Network

3.2.1 Based on Types of Actors



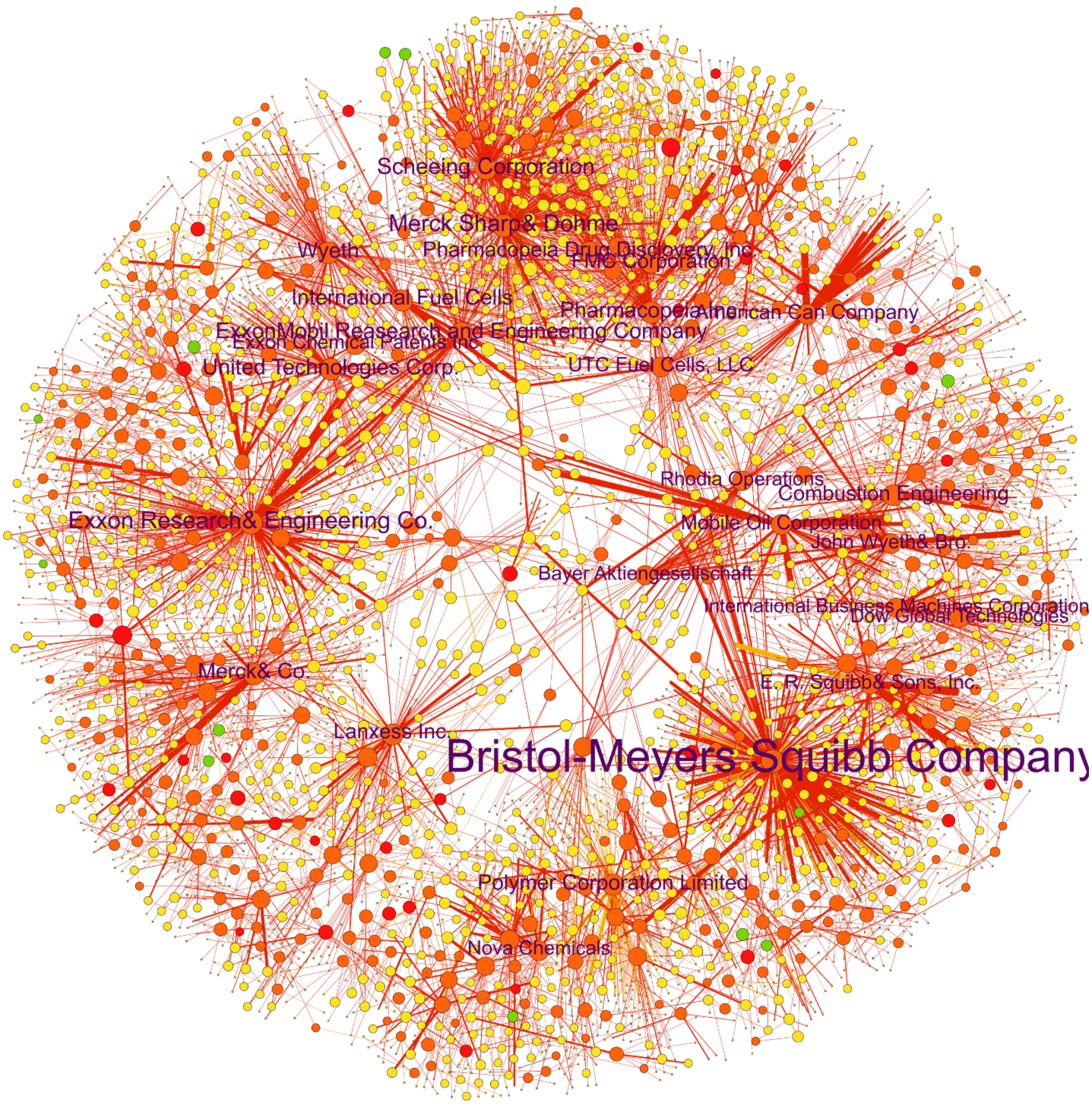
3.2.2 Based on Regions



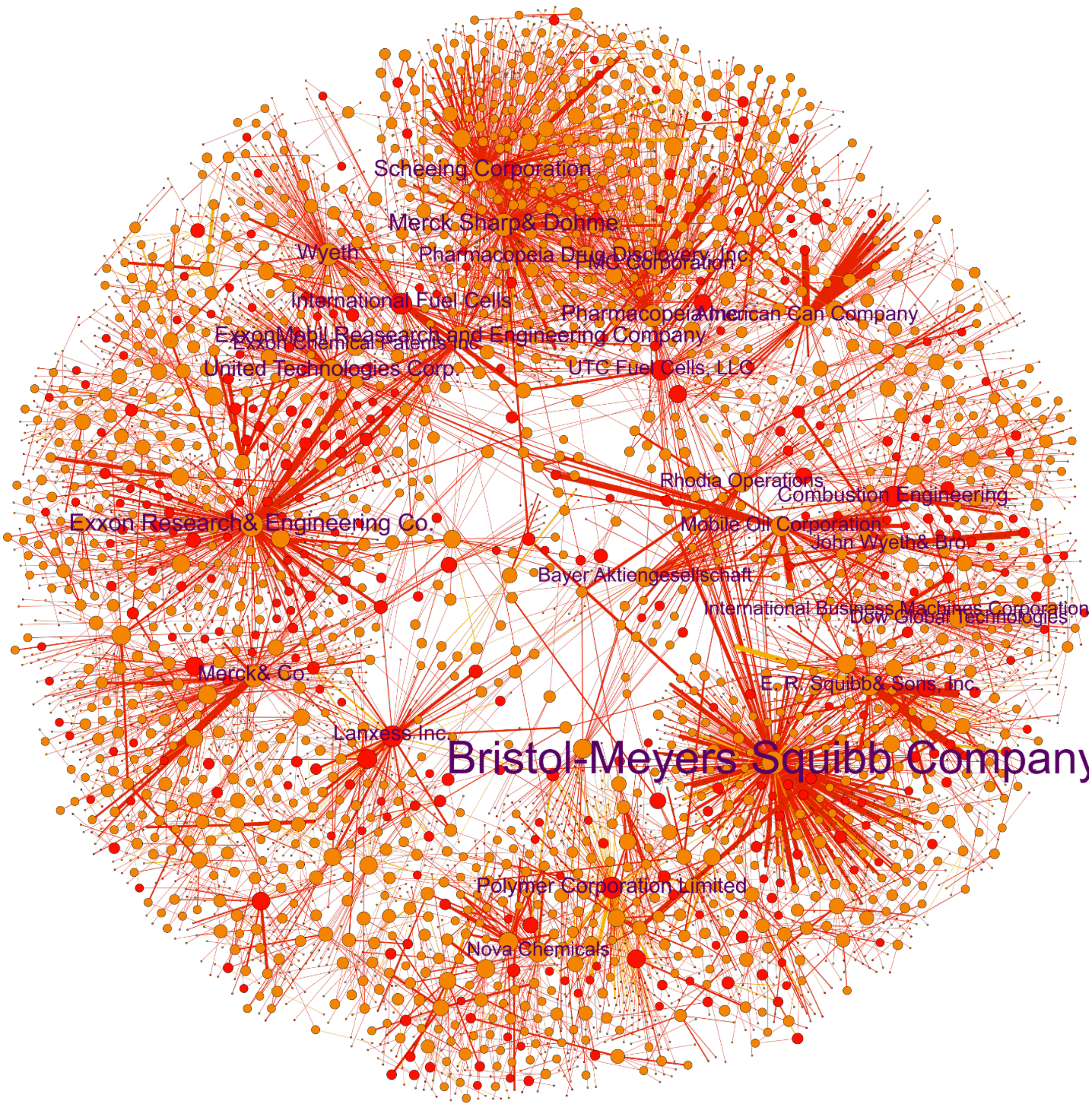
Appendix.4 Networks for the Windsor-Sarnia Region

4.1 Overall Network

4.1.1 Based on Types of Actors

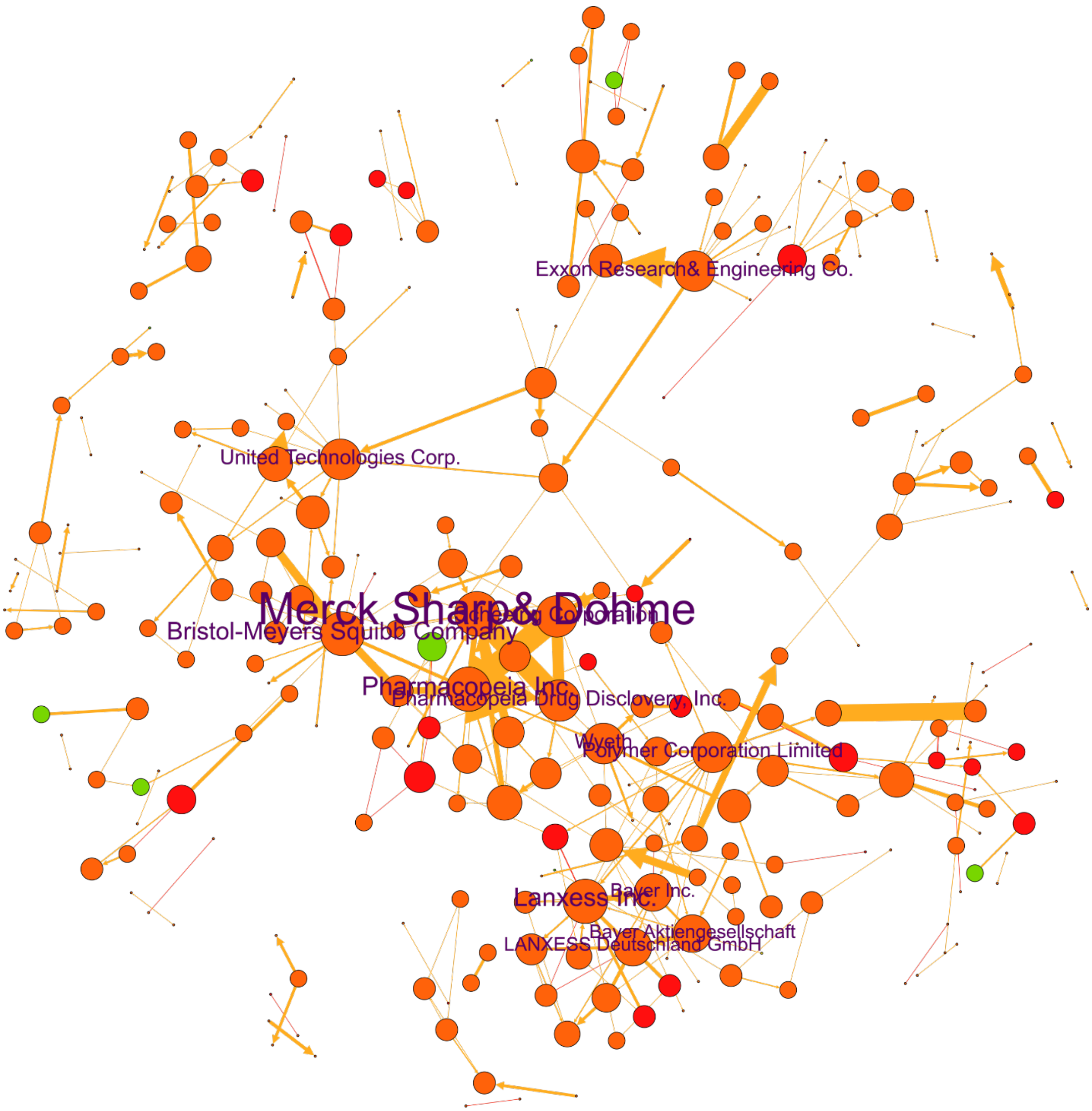


4.1.2 Based on Regions

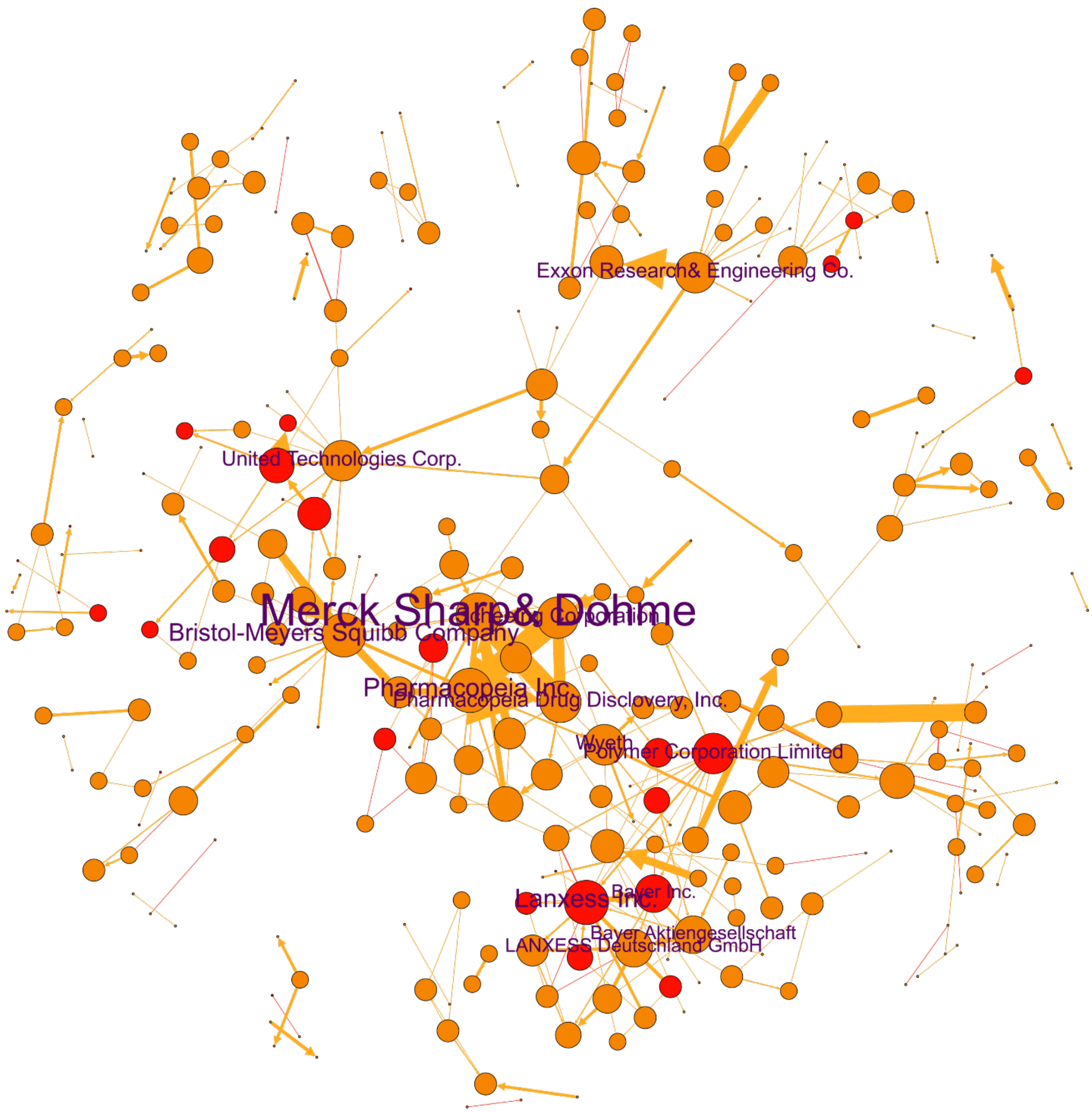


4.2 Mobility Network & Cooperation Network

4.2.1 Based on Types of Actors



4.2.2 Based on Regions



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