Knowledge Creation and Sharing: Geographical and Network Perspectives

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ABSTRACT

This paper brings together our findings on the importance of the geographical proximity and the network structure in the knowledge creation and sharing in Canadian biotechnology and nanotechnology. We find that most of the knowledge sharing occurs inside the geographical clusters or in the proximate distance. However, very distant or overseas collaborations are preferred over the mid-range distance options. We examine the structural properties of the knowledge networks and relate them to their efficiency in knowledge creation and transmission. We conclude that both geographical and network dimensions promote innovation and propose to search for individuals who span the two dimensions.

Keywords
Knowledge sharing, knowledge network, geographical pattern, innovation, biotechnology, nanotechnology

1.0 INTRODUCTION

It is well established in economic geography to view regions as key drivers of innovation. This is built on the fact that geographical proximity facilitates knowledge sharing, since knowledge does not spill over large distances (Audretsch and Feldman, 1996; Jaffe and Trajtenberg, 1996). It is assumed that all firms in the cluster can benefit from these localized knowledge spillovers, which are not available to the firms outside the clusters. As a consequence, the firms in clusters are found to be more innovative (Baptista and Swann, 1998). However, Boschma (2005) suggests that this view overemphasizes the role of geographical proximity in the transfer of knowledge between firms. He argues that other dimensions of proximity should be taken into consideration as well, since geographical proximity per se is neither a necessary nor a sufficient condition for learning to take place.

Another stream of literature on knowledge creation and diffusion emphasizes the role of cognitive proximity. Some researchers (for example Breschi and Lissoni, 2001; Lissoni, 2001; Cowan *et al*., 2000) argue that it is not geographic proximity which causes tacit knowledge to spill over between firms, but it is social connectedness of people in the network. Knowledge circulates and flows through the networks between the actors who are not necessarily placed in the same location. Technical or scientific knowledge is highly specific and its jargon differs from the jargon of the broader social community. The ones who understand it are the members of closed, restricted, but geographically dispersed "epistemic community", within which the tacit messages can be easily transmitted even if knowledge links take place among agents located far away in space. The networks thus do not require co-location of the actors for the production of innovation. On the other hand, physical proximity does not imply epistemic proximity, because epistemic communities are never as wide as to include all members of a local community. This means that individuals in clusters may be excluded from knowledge sharing when they are not part of knowledge networks.

Apparently, the two concepts seem to stand against each other. Does it matter more for an inventor to be in the right location or to be connected to the right network of people? This paper brings together our findings on both the importance of geographical proximity and the significance of the structure of the innovation networks. An important contribution to the advancement of knowledge is achieved by considering both the geographical and network aspects of innovation at the same time. The main objectives of this research are to examine the transmission of knowledge through collaboration inside and outside Canadian biotechnology and nanotechnology clusters and to investigate the role of the structure of the collaboration networks in the knowledge creation and diffusion.

2.0 DATA METHODOLOGY

The networks of Canadian biotechnology and nanotechnology inventors were constructed from the patent co-inventorship data using information contained in 3550 biotechnology and 1968 nanotechnology patents registered at the United States Patent and Trademark Office (http://www.uspto.gov/). We assumed that in order to produce a patent, the inventors have to create, share and transmit knowledge among themselves. The patent co-inventorship connections thus well document the knowledge sharing patterns. Social network analysis was then used to study the collaborative behavior of the inventors within and among clusters and the social network analysis software PAJEK was used to visualize the network patterns and to analyze the network properties.

3.0 GEOGRAPHICAL PERSPECTIVE

Innovative activity in Canada is concentrated in several locations which roughly correspond to the larger metropolitan areas: 12 biotechnology and 8 nanotechnology clusters have been identified. In biotechnology, more than half of all Canadian inventors reside in three largest clusters - Toronto, Montreal and Vancouver, but in nanotechnology it is mainly the Toronto cluster which dominates the industrial sector since around one quarter of all Canadian inventors reside there.

In this section we analyze the geographical pattern of knowledge sharing and diffusion, which is based on the analysis of the collaboration instances. A collaboration instance is a connection between a pair of inventors for the purpose of knowledge sharing and knowledge creation, which finally leads to a co-invention of a patent. We divided the collaboration instances according to the location where they take place into the intra-cluster collaborations (both inventors in a collaborating pair are from the same cluster), inter-cluster collaborations (one of the inventors in a pair resides in a different cluster or elsewhere in Canada) and international collaborations (one of the inventors in a pair resides abroad). Figure 1 presents the overall collaboration pattern for Canadian biotechnology inventors. The collaboration pattern in nanotechnology is not shown here, but the percentages are very similar. Well over half of the all collaboration instances take place inside the clusters and less than one third are distant ties directed abroad. Only 11%-12% of all the collaboration involves inventors from other Canadian clusters or from elsewhere in Canada. Most of the foreign collaborative ties in both technologies are linked to the American inventors. The remaining international cooperation ties include collaborators from France, Great Britain, Australia, Germany and Japan.

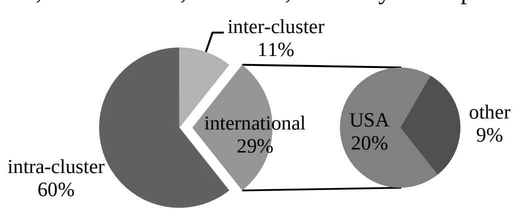
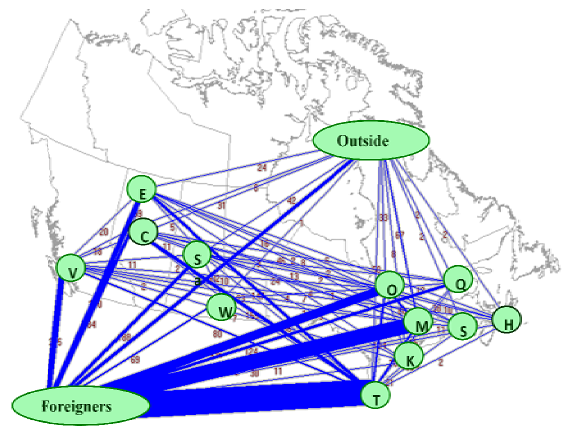


Figure 1: Overall pattern of knowledge sharing in Canadian biotechnology

Figure 2 shows the knowledge sharing among inventors of 12 biotechnology clusters inside Canada. Each link between two clusters represents an existence of collaboration relations between these two clusters and the strength of the line represents the relative frequency of that cooperation. To put the inter-cluster collaboration into perspective, international collaborations were included in the figure as well in the grouping called "Foreigners". A great part of knowledge sharing among biotechnology inventors takes place over the Canadian border (usually with the US). All the collaboration ties of the inventors residing outside the 12 identified clusters are grouped in "Outside" group. There is not much knowledge sharing between these inventors and the ones located in clusters. Similar results, not shown here, were obtained for the geographical pattern of knowledge sharing in nanotechnology.



V…Vancouver	E…Edmonton	C…Calgary
S… Saskatchewan	W…Winnipeg	O…Ottawa
T…Toronto	K…Kingston	M…Montreal
Q…Quebec	S…Sherbrooke	H…Halifax

Figure 2: Pattern of knowledge sharing among Canadian biotechnology clusters and foreigners

3.1 Distance-Based Analysis

Given the specific geographical aspects of Canada (concentration of a great majority of its inhabitants along the southern border), the collaboration analysis based on political divisions *(e.g.,* national versus international cooperation) does not actually tell a complete story about the distances between the collaboration partners. Many of the Canadian biotechnology and nanotechnology clusters are located in a proximate distance from the US border and an international collaboration partner thus can be the closest one. Therefore, all the out-of-cluster collaborations (including both international and inter-cluster ones) have been divided into four groups according to the distance between the residences in each collaborative pair: short range (distance < 600km), mid-range (600km < distance < 1600km), long range (distance > 1600km) and overseas (outside North America).

Figure 3 shows the proportions of these collaborations for the inventors in each biotechnology cluster (the results for nanotechnology are not shown here). Almost 60% of all the out-of-cluster collaborations of Canadian biotechnology inventors (50% for nanotechnology) involve partners residing more than 1600km apart. Most of these distant partners live in Canada or the USA, but around one third of these collaborations link Canadians with overseas inventors. Mid-range collaborations are considerably less popular for both biotechnology (12%) and nanotechnology (8%) fields. Much more frequent are joint research projects with geographically more proximate partners located in the distance shorter than 600km (28% in biotechnology and 42% in nanotechnology).

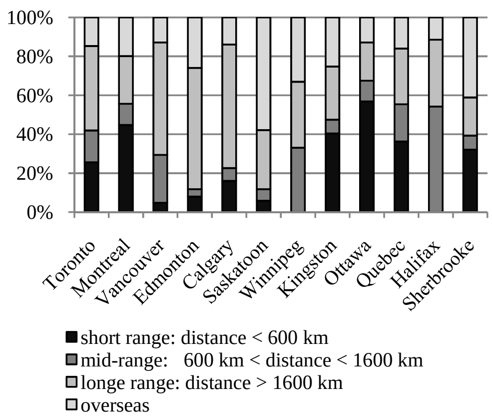


Figure 3: Proportions of all out-of-cluster collaborations in biotechnology based on the distance

4.0 NETWORK PERSPECTIVE

In this section we explore the network patterns of the knowledge sharing and its diffusion through Canadian biotechnology and nanotechnology inventors.

4.1 Collaboration characteristics

Here the vertices in the created knowledge networks represent inventors, while links between them represent collaborative relations. The main objective consists in the study of knowledge flows and information exchange among the researchers, *i.e.* in the characterization of the links. For instance, it was found that more than one third of all collaborative relations between pairs of inventors involve repetitive instances of collaboration. In some cases the cooperative relationships actually seem to be very fruitful, as the most frequent collaboration between a pair of inventors was repeated 50-60 times. Most of the relationships between a pair of inventors are, however, single collaboration instances (i.e., they resulted in only 1 patent). An inventor in Canadian biotechnology knowledge network has on average 4.26 collaboration partners (5 in nanotechnology), but some of them have a considerably higher number of relationship ties, the highest one amounting to 66 co-inventors (54 in nanotechnology). Canadian inventors most commonly have one, two or three collaborators. Only a small amount of inventors called isolates do not collaborate with anybody else on their patent(s), and only a few have more than 10 co-inventors. These characteristics are quite comparable for both networks.

Table 1: Collaboration characteristics in the networks

	Biotechnology	*Nanotechnology*
Number of inventors	4569	1968
Number of patents	3550	1443
Collaborating pairs	9731	4920
% of repeated collaborations	36%	34%
Max of repeated collabor.	60	50
Collaborators per inventor	4.26	5
Co-inventors in a patent	3.09	3
Collaborations per inventor	7.46	8.6

4.2 Fragmentation of the Networks

Fragmentation of a network is based on the characteristics of network components. A component is defined as the maximal connected subnetwork (Wasserman and Faust, 1994). It is a part of the network in which all inventors are directly or indirectly interconnected and it is thus supposed that they all actively share their knowledge. The basic characteristics related to the components are shown in Table 2, which suggests that the knowledge networks are quite fragmented and that inventors are not highly interconnected. The biotechnology network seems to be slightly less fragmented than the nanotechnology one. The average component size in nanotechnology is somewhat smaller, while the share of the components which include 50% of all the inventors is much higher in nanotechnology network.

Table 2: Fragmentation of the knowledge networks

	Biotechnology	*Nanotechnology*
Number of components	894	407
Size of largest comp. (as %)	579 (13%)	336 (17%)
Ratio of 2^{nd} / 1^{st} largest comp.	0.32	0.09
Average component size	5.11	4.84
Share of comp. with 50% inv.	10%	26%
Isolates as % of inventors	4%	4%

In nanotechnology there appears to be a well interconnected network component in Toronto, but the rest of the nanotechnology inventors are working in relatively disconnected groups. This was expected. The specialization fields within biotechnology are quite close in their scientific nature and are often overlapping. The inventors in the biotechnology network should thus be more interconnected between each other. Nanotechnology, on the other hand, includes many very disparate fields, where the inventors understandably work in more separated groups. Nanotechnology would therefore appear more as a brand name than a "single" technology so far.

4.3 Structural Cohesion of the Networks

Structural cohesion (density) refers to the degree to which vertices are connected among themselves. We measured the density by the *average degree of a network*. The degree of a vertex is the number of links that are directly connected to that vertex (Wasserman and Faust, 1994). It represents the number of direct collaborators with whom an inventor cooperated on at least one patent. The more co-inventors the inventors have, the tighter is the network structure. Since the biotechnology network is older, contains more inventors and is more developed, it was expected to find it to be also denser, while the connections between the subjects in the nanotechnology network were assumed to be much looser. However, this was not confirmed (see Table 3). We discovered that this is caused mainly by very high cohesion among the nanotechnology inventors in the Toronto subnetwork.

4.4 Centralization of the Subnetworks

A highly centralized network has a clear boundary between its center and its periphery. The center of a centralized network allows more efficient transmission of knowledge. A network is more centralized if centralities of the vertices vary substantially. Two main measures of network centralization were used: degree centralization and betweenness centralization. *Degree centralization* of a network is based on the variation in degrees of vertices in a network, whereas *betweenness centralization* is based on the variation in betweenness centrality of vertices in the network. Betweenness centrality of a vertex is defined as a proportion of all shortest distances between pairs of other vertices that include this vertex (de Nooy *et al.,* 2004). An inventor is more central if a lot of shortest paths between pairs of other inventors in the subnetwork have to go through him. Betweenness centrality is therefore based on the inventor's importance to other inventors as an intermediary and it measures his control over the interactions between other inventors and thus over the flow of knowledge in the subnetwork. In general, the biotechnology network has more highly central inventors than the nanotechnology network. As for the centralization measures, the degree centralization indicator favors the nanotechnology network, whereas the betweenness centralization indicators show the reverse. As betweenness centralization refers to the positions of its inventors as intermediaries, it was not expected that the nanotechnology network would score higher because of its already mentioned disciplinary fragmentation.

4.5 Geodesic Distances in the Networks

A shortest path between two vertices is referred to as geodesic. The geodesic distance is then the length of a geodesic between them, which depends on the number of intermediaries needed for an inventor to reach another inventor in the subnetwork. A short path length in innovation networks should improve knowledge production and knowledge diffusion (Cowan and Jonard, 2004; Fleming *et al.,* 2006), since knowledge can move to the different parts of a network more quickly and spread rapidly among inventors. Moreover, as Cowan and Jonard (2004) suggest, decreased path length will cause knowledge to degrade less by bringing new sources of ideas and perspectives from farthest parts of the network to the inventors. The longest geodesic in a network (the longest shortest path) is called the *diameter of a network*. It quantifies how much apart are the two farthest vertices in a network and it is a rough indicator of the effectiveness of a network in connecting pairs of inventors. The observed diameters in both networks seem to be fairly long when compared to the overall size of the networks, which suggests a quite low connectedness in the subnetworks. An indicator of the *average distance* of a network, which denotes an average of all the distances of all the vertices in the subnetwork, is a more global measure of efficiency in communication. Nevertheless, the distance between two unconnected vertices is not defined (does not exist) and the average distance hence could be measured only in fully interconnected networks. The average distances were therefore calculated only between reachable vertices (*i.e.,* directly or indirectly connected). The *reach of a vertex* is defined as the number of vertices that can be reached from this particular vertex. Table 3 shows the maximal reach for each network, *i.e.* the maximum number of reachable inventors within a network. Evidently, more inventors could be directly or indirectly reached in larger networks. As expected, the biotechnology network shows longer geodesic distances but also a much longer maximal reach. Knowledge should thus flow faster in nanotechnology knowledge networks.

4.6 Cliquishness in the Networks

Cliquishness is a property of a local network structure which refers to the likelihood that two vertices that are connected to a specific third vertex are also connected to one another. Cliquish networks have a tendency towards dense local neighborhoods, in which individual inventors are better interconnected with each other. Such networks exhibit a high transmission capacity, since a great amount of knowledge could be diffused rapidly (Burt, 2001). Moreover, a high degree of cliquishness in an innovation network supports friendship and trust-building, and hence facilitates collaboration between innovators. Uzzi and Spiro (2005) and Schilling and Phelps (2007) argue that higher cliquishness enhances system performance and knowledge diffusion. However, Cowan and Jonard (2003) and Fleming *et al.* (2006) point out the existence of negative effects of cliquishness. The role of a high degree of cliquishness in the innovation production is still not obvious and the optimal degree will apparently depend on a variety of factors. We measured the degree of local cliquishness for each vertex with the egocentric density of a vertex, which is the fraction of all pairs of the immediate neighbors of a vertex that are also directly connected to each other, and then the *average egocentric density of a network* was calculated. Both biotechnology and nanotechnology show quite comparable results for the network cliquishness (see Table 3).

Table 3: Other network structure characteristics

	Biotechnology	*Nanotechnology*
Network density	0.001	0.003
Average degree	4.26	5
Degree centralization	0.01	0.02
Betweenness centralization	0.009	0.006
Network diameter	17	17
Average distance	6.55	4.16
Max reach	578	355
Cliquishness	0.71	0.76

5.0 CONCLUSIONS

The main objective of this paper was to explore two perspectives from which knowledge sharing and knowledge creation could be studied – the geographical pattern and the network structure. It was found that most of the scientific knowledge sharing which involves Canadian biotechnology and nanotechnology inventors takes place inside clusters. Canadian inventors who decide to build cooperation ties outside their clusters usually prefer to do so with collaborators from abroad, mainly from the US. A distance-based analysis confirms an important role of the geographical proximity when searching for a cooperation partner. Nevertheless, this importance significantly decreases when no partners are found within 600 km. Very distant or overseas collaborations are then preferred while the mid-range distance options are overlooked.

The second perspective involved the analysis of knowledge networks. The structural properties of both biotechnology and nanotechnology knowledge networks were examined and then related to the efficiency in knowledge diffusion and innovation creation. It was observed that in order to enhance the efficiency of each network in terms of knowledge diffusion, the network should be cohesive (which means that inventors are closely interconnected), cliquish (which fosters trust and close collaboration), it should have a long reach within large components (which enables bringing fresh and non-redundant knowledge from distant locations) and it should have a centralized structure (which supports fast knowledge transmission). The comparative analysis between biotechnology and nanotechnology innovation networks revealed that the biotechnology network is larger and more developed than the nanotechnology one. It is also less fragmented due to the scientific nature of the biotechnology specialization fields which are often overlapping. Nanotechnology, in contrast, includes many quite disparate fields, where the inventors work in more separated groups.

We noted that the geographical analysis did not produce any specific industry-related results, since the conclusions regarding the geographical pattern and the behavior of the inventors when seeking knowledge sharing partners were the same for biotechnology and nanotechnology. However, the network analysis of the knowledge sharing and creation revealed quite different patterns for each technology. These gave us valuable insights into the knowledge sharing organization in both technologies.

Having summarized the two perspectives we can now answer the question asked in the beginning: Does it matter more for an inventor to be in the right location or to be connected to the right network of people? We have clearly shown that the geographical distance does play a very important role. Also, the analysis brought to light the fact that the most successful inventors are also the most interconnected ones. Therefore, we propose that both the geographical concept and the concept of network are at utmost importance for the knowledge creation and diffusion. Both geographical and cognitive dimensions nurture the growth of the cluster and promote innovation through a dynamic interaction of the actors localized in clusters who absorb external knowledge through the local and non-local networks. In order to bring the new knowledge to the cluster the inventors thus have to be well connected both inside and outside the clusters. Currently we are working on the identification of the individuals who are most critical for the knowledge growth in the cluster because of both their geographical location and their position in the knowledge network. These inventors enable the crucial nurturing of their own clusters with fresh knowledge originating outside.

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