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The Superclusters Initiative: An Opportunity to Reinforce Innovation Ecosystems

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ABOUT THIS STUDY

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The Partnership for the Organisation of Innovation and New Technologies (4POINT0) has five-year funding from the Social Sciences and Humanities Research Council (SSHRC) to explore how Canada can benefit from its strength in science and technology, build dynamic innovation ecosystems to take advantage of disruptive new technologies, and contribute to innovation and strong economic growth. Exploiting big data analytics, 4POINT0 partners will also collect and analyze data on innovation to propose, develop, test and validate new and more appropriate indicators to monitor the innovation performance of key Canadian innovation ecosystems.

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SUMMARY

It is a well-known fact that, for some time, Canada has been performing below expectations when it comes to turning its excellent science and technology into innovation. This is worrisome because we also know there is a positive relationship between scientific research, technological innovation and economic growth.

The Innovation Superclusters Initiative, put forward by the federal government in 2017, is the centrepiece of its plan to reverse Canada's deteriorating innovation performance, accelerate the adoption by Canadian firms of several key transformative technologies and foster a strong entrepreneurial or start-up culture. Under this initiative, Ottawa is investing $950 million over five years to support five superclusters involving small, medium-sized and large companies, academic institutions and not-for-profit organizations from across the country. But how will we know if the program has achieved its objectives?

In this study, Catherine Beaudry and Laurence Solar-Pelletier argue that the superclusters are in fact innovation ecosystems; and that is the lens through which their performance should be monitored and assessed. More broadly, they view the superclusters initiative as somewhat of a Canadian experiment, providing all stakeholders with a unique opportunity to identify the factors that facilitate the emergence and success of innovation ecosystems, and allowing policy-makers to better design and fine-tune innovation policies and programs.

According to the authors, the use of the term "innovation ecosystem" has become quite common among academics, practitioners and policy-makers, but the concept is still not well defined. They make the case that, to fully understand why and how innovation ecosystems can help boost Canada's innovation capacity, one must first understand the theoretical foundations on which they are built. These range from industrial clusters and knowledge networks to collaboration and open innovation. The literature they survey strongly hints at the potential benefits of innovation superclusters. However, their true economic impact has yet to be measured.

After reviewing several of the key performance indicators to be used by the government to track the progress of the superclusters, Beaudry and Solar-Pelletier conclude that these consist mainly of generic indicators, which broadly cover the main goals of the initiative but overemphasize basic metrics such as the number of participating companies and organizations as well as new products, processes and jobs created. As they point out, although such indicators may be relatively easy to quantify, they are at best proxies for innovation and its impact. They overlook key elements that matter a lot in understanding innovation outcomes, such as the nature of the links and relationships among ecosystem constituents, the innovative capacity of the people involved, and the extent of knowledge transfer and technology adoption taking place.

Since the initiative was launched, Innovation, Science and Economic Development Canada has been consulting with experts and working with members of the five superclus-

ters to develop a more detailed and precise set of performance indicators. Beaudry and Solar-Pelletier urge all stakeholders to continue to work together to design and test new indicators that are better adapted to the reality of innovation ecosystems. This would enable them to truly measure the impact and potential of these ecosystems and to adapt innovation practices and policies accordingly. The authors are currently working on developing such metrics as part of a five-year research project conducted by the Partnership for the Organisation of Innovation and New Technologies.

Gaining a better understanding of supercluster dynamics will benefit all the players involved, including policy-makers. The degree of coordination and insight required to ensure the success of the superclusters, or to propose how to change tack in real time if need be, is unprecedented. So too is the task entailed in accurately measuring that success.

RÉSUMÉ

Il est bien connu que le Canada peine depuis longtemps à transformer en innovation ses fortes capacités en science et technologie. Cette situation est d'autant plus préoccupante que nous savons qu'il existe une corrélation positive entre recherche scientifique, innovation technologique et croissance économique.

Lancée par Ottawa en 2017, l'Initiative des supergrappes d'innovation est la pièce maîtresse du programme fédéral visant à inverser cette tendance de la performance canadienne, à accélérer l'adoption de technologies transformatrices par le secteur privé et à promouvoir une solide culture d'entreprises en démarrage. C'est ainsi qu'Ottawa investira 950 millions de dollars sur cinq ans en appui à cinq supergrappes regroupant des petites, moyennes et grandes entreprises, des établissements universitaires et des organismes à but lucratif et non lucratif de tout le pays. Mais comment saurons-nous que ce programme a rempli ses objectifs ?

Catherine Beaudry et Laurence Solar-Pelletier soutiennent dans cette étude que les supergrappes constituent en fait des écosystèmes d'innovation. C'est donc sous cet angle qu'il faudrait suivre leur évolution et mesurer leur efficacité. Plus généralement, elles voient l'initiative fédérale comme une expérimentation canadienne à grande échelle offrant à tous ses participants la chance unique de cerner les facteurs qui favorisent la création puis la réussite de ces écosystèmes, tout en permettant aux décideurs d'améliorer l'élaboration et la mise au point de leurs politiques et programmes d'innovation.

Si l'usage du terme « écosystème d'innovation » s'est répandu parmi les chercheurs, spécialistes et décideurs, notent les autrices, le concept lui-même reste mal défini. Or, pour déterminer comment et pourquoi ces écosystèmes peuvent stimuler notre capacité d'innovation, il faut d'abord en étudier les fondements théoriques, qui vont des grappes industrielles aux réseaux de savoirs en passant par la collaboration et

l'innovation ouverte. La recherche explorée pour cette étude tend à confirmer les avantages des supergrappes d'innovation, mais leurs véritables retombées restent à mesurer.

À l'examen des indicateurs de performance que compte utiliser le gouvernement pour suivre le progrès des supergrappes, les autrices observent qu'il s'agit surtout d'indicateurs génériques applicables aux grands objectifs du programme, mais qui donnent trop d'importance à des paramètres élémentaires comme le nombre d'entreprises ou d'organisations participantes et la création de nouveaux produits, processus et emplois. Il s'agit certes d'indicateurs relativement simples à quantifier, mais qui témoignent tout au plus des manifestations et non des effets réels de l'innovation. Entre autre, ils font abstraction d'éléments clés qui permettraient d'en mesurer les résultats, notamment la qualité des liens et relations entre les composantes d'un écosystème, la capacité d'innovation de ses participants et l'étendue du transfert de connaissances et de l'adoption de technologies.

Depuis le lancement de l'initiative, le ministère de l'Innovation, des Sciences et du Développement économique a consulté des experts et des membres des cinq supergrappes en vue d'établir des indicateurs plus précis et plus détaillés. Les autrices exhortent tous les intéressés à poursuivre leur collaboration pour définir et évaluer de nouveaux indicateurs mieux adaptés à la réalité des écosystèmes. On pourrait ainsi mesurer véritablement leur incidence et leur potentiel, puis adapter en conséquence nos pratiques et politiques. Signalons que les autrices travaillent elles-mêmes à l'élaboration de tels paramètres dans le cadre d'un projet de recherche de cinq ans du Partenariat pour l'organisation de l'innovation et des nouvelles technologies.

Une compréhension plus approfondie de la dynamique des supergrappes profitera à toutes les parties prenantes, y compris à nos décideurs. Le niveau de coordination et d'information nécessaire à leur réussite, ou à leur rapide réorientation stratégique, est aujourd'hui sans précédent. Et la tâche d'en évaluer précisément les résultats revêt une importance tout aussi décisive.

INTRODUCTION

Canada has been performing below expectations when it comes to turning its excellent science and technology into innovation. This is worrisome because there is ample empirical evidence of a positive relationship between scientific research, technological innovation and economic growth.[1] Canada does well in terms of science and technology outputs. It ranks 5th worldwide in the number of publications per thousand inhabitants, 6th for research impact and 11th in the share of patents filed at three major patent offices, known as triadic patents (Council of Canadian Academies 2018; OECD 2014). But both gross domestic expenditure on research and development and business expenditure on research and development as percentages of gross domestic product are declining (OECD 2017). Canada's ranking in innovation is also falling. Its commercialization successes are limited and the rate of cluster development is low (Canada 2016; Schwab 2019). This jeopardizes the country's ability to innovate.[2]

In addition to having difficulty translating science and technology performance into efficient solutions and commercial successes, the country is dealing with the rapid dissemination of discontinuous and potentially disruptive technologies.[3] These include big data analytics; artificial intelligence (AI); the Internet of things; advanced materials; additive manufacturing such as 3D printing; and blockchain, a digital ledger of transactions duplicated and distributed across a computer network. These technologies are drastically changing the way firms are designing, prototyping, testing and manufacturing new products and services. As Daniele Archibugi wrote in 2017: "One of the key characteristics of disruptive technologies is that they do not knock gently at the door: they enter social and economic life suddenly and unexpectedly" (2017, 541). Clear illustrations of this phenomenon include the emergence of Uber, the exponential doubling of computer chip power and the rapid advances in DNA sequencing.

Schumpeterian creative destruction forces such as autonomous vehicles, personalized medicine and the ongoing automation of traditional manufacturing and industrial processes using smart technology are forcing businesses and public organizations to rethink how they generate ideas and innovate. Governments are also under pressure to provide better adapted regulation and innovation policies. Given their slow rates of technology adoption, most Canadian firms appear ill equipped to overcome the challenges that stem from these technologies. Canada's innovation policy framework needs to be redesigned to accommodate new ways of organizing and governing innovation.

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1 See, for example, Autio and Thomas (2014); Mowery and Ziedonis (2002); and Sorenson and Fleming (2004).

2 The fact that Canada's stellar performance in science and technology does not translate into an equally stellar performance in innovation still puzzles policy-makers and decision-makers. The 2018 report produced by the Council of Canadian Academies' Expert Panel on the State of Science and Technology and Industrial Research and Development in Canada is the most recent attempt to shed light on the matter (CCA 2018).

3 Discontinuous technologies are those that do not follow the expected evolution of existing technologies (see, for example, Bessant 2005). On the disruptive impacts of new technologies, see Christensen (2013); Christensen, Raynor and McDonald (2015); and Christensen, Raynor and McDonald (2011).

The Innovation Superclusters Initiative, which was put forward by the federal government in 2017, is the centrepiece of its plan to resolve Canada's innovation paradox (Canada 2017b). Under this initiative, Ottawa is investing $950 million over five years to support five superclusters involving small, medium-sized and large companies, academic institutions and not-for-profit organizations. Each supercluster has its own focus: digital technologies, protein industries, next-generation manufacturing, supply chains powered by AI, and ocean technologies. The government says its aim is to promote commercial innovation and global presence, from ideation to value creation, while providing the means to organize innovation ecosystems to collectively face and benefit from groundbreaking technologies.[4] The objectives of the initiative are quite ambitious. The superclusters are expected to increase business spending on research and development, promote widespread collaboration, attract and retain the right talent, and increase the size and global reach of firms.

Increasing domestic firms' size and reach, also called scaling up, has been a top priority for decades for most countries. Yet Canada still fails to produce multinationals. Repeatedly hammering the same "scaling up" nail has not provided the expected benefits. It is time to try something else. We at the Partnership for the Organisation of Innovation and New Technologies hypothesize that the advantages accrued from collectively developing and commercializing innovations within ecosystems may counterbalance the extent of scaling up required, or expected, of firms to succeed. The superclusters initiative might prove that well-organized innovation ecosystems provide the necessary agility and performance to become engines of economic growth and wealth creation in the country. Working together could yield a collective performance that is larger than the sum of its parts, a win-win situation for the ecosystem and its constituents. In our view, the concept of innovation ecosystems provides the appropriate framework to rethink Canada's innovation strategy.

Even though the name of the initiative includes the word "cluster", the superclusters are in fact more akin to innovation ecosystems. Unlike clusters, they are not locally or geographically constrained, and many of their constituent members are part of extensive networks of national and international firms or organizations. The concept of ecosystem, and more specifically of innovation ecosystem, is increasingly used by academics, practitioners and policy-makers. It provides a new lens for studying and understanding innovation that goes beyond clusters or networks. However, the concept is still not well defined and understood. And the empirical tools to measure its broad impact have yet to be designed. In this study, we briefly survey the relevant literature on clusters and superclusters, or innovation ecosystems, to examine the theoretical and empirical foundations that underlie the government's initiative. We then explore the challenges and opportunities presented by this novel policy approach.

4 For more details on the *Innovation Superclusters Initiative* and on the five Canadian superclusters, consult the government's website: https://www.ic.gc.ca/eic/site/093.nsf/eng/00017.html

THE BUILDING BLOCKS OF INNOVATION ECOSYSTEMS

While the concept of an innovation ecosystem was inspired by ecology, its foundations within the economics and management sciences derive from numerous strands of the literature that study and describe the way individuals and organizations interact and collaborate formally and informally. The theoretical foundations of the concept span industrial clusters, knowledge networks, geographic, social and cognitive proximities, collaboration and open innovation — all of which have been shown to have a positive impact on a firm's propensity to innovate. To fully understand why and how innovation ecosystems have the potential to boost Canada's innovation capacity, it is important to understand the foundations on which they are built.

Industrial clusters

There has long been a strong interest in clusters within the scientific community and among policy-makers. Since Michael Porter introduced the idea of clusters in 1990, few economic concepts have provoked such enthusiasm. Still, the benefits of clustering were studied long before Porter's seminal work. He drew on the work of Alfred Marshall who, in his 1890 book *Principles of Economics*, emphasized the importance and advantages of geographical proximity for economic growth in reducing transportation and other transaction costs. Porter initially defined an industrial cluster as a group of geographically colocated, interconnected firms and organizations within a sector that share common elements and are complementary to each other. Silicon Valley is a well-known and envied example of a highly efficient and productive cluster. Other names have been given to this local concentration of enterprises, skills, cooperation and competition, including regional systems of innovation (Lundvall 1992), flexible specialization (Piore and Sabel 1984), smart specialization (Foray 2014) and industrial districts (Beccatini 1990). These concepts all focus on the importance of geographical proximity, which allows trust-building among stakeholders and access to a highly specialized labour force.

Research has shown that firms that operate in clusters are more innovative than firms that operate in isolation. They generate more patents and have greater employment and revenue growth, partly due to specialization or diversification effects.[5] The presence of strong research universities as integral parts of clusters increases the propensity of small, local firms to patent and that of universities to coevolve along with local, private sector patenting (Helmers and Rogers 2015; Blankenberg and Buenstorf 2016). Silicon Valley would not be the same without the fundamental role played by Stanford University and the University of California, Berkeley. Researchers and students created spinoffs and start-ups, and went back and forth between private enterprises and the universities.

[5] For more on the benefits of clusters, see Beaudry and Breschi (2006); Beaudry and Swann (2009); and Delgado, Porter and Stern (2014). A cluster is considered specialized if there is a higher concentration of a given industry in the cluster compared with the rest of the region or country. It is considered diversified if composed of a multitude of sectors with enough critical mass (Beaudry and Schiffauerova 2009).

The better performance of firms located in clusters is generally attributed to the geographical proximity that defines them. Reducing the distance of interactions improves coordination between members of the cluster and facilitates the sharing of tacit knowledge gained through experience or shared expertise (Bathelt and Cohendet 2014; Gertler 2003). But geographical proximity is by no means essential when knowledge is exchanged more formally (Bathelt and Henn 2014). In other words, clusters are not a universal panacea.

Since Porter's seminal work, interpretations of the concept of "cluster" have multiplied and evolved to incorporate other types of proximity. The literature has shown that the degree of geographical proximity varies across local systems of innovation, or innovation clusters.[6] Table 1 portrays a four-quadrant framework for clusters. It was developed by André Torre in his 2006 work *Clusters et systèmes locaux d'innovation*. This framework helps us analyze two crucial dimensions of innovation clusters: the degree of colocalization or *geographical proximity* and the degree of organization of interfirm links or *organizational proximity*. The latter refers to the capacity to coordinate the transfer and exchange of information and knowledge either within or between organizations (Boschma 2005). Establishments within the same firm that share a common organizational culture are more likely to have strong links. So too do firms that share a common knowledge space and have developed formal collaborative agreements. This conceptual framework can be used to compare clusters and innovation ecosystems, as it shows there are various ways to organize both.

Table 1. Cluster types

		Organization of interfirm relations	
		Strong	Weak
Localization of interfirm relations	Strong	(1) Cluster à la Porter	(3) Cluster linked to a local resource
	Weak	(2) Cluster without proven local base	(4) Dispersed activities

Source: Torre (2006).

Quadrant 1 represents clusters as defined by Porter. They rely to a significant degree on colocation and strong organizational ties. Emerging clusters very likely start this way, with strong relationships between a few local actors. They are often the result of a specific regional policy to create a cluster. Silicon Valley fits in this category. Quadrant 2 illustrates the case of clusters with weak local anchoring and strong interfirm relations. These clusters can exist at a national and regional level. They are more akin to knowledge or innovation networks. The development and production of Airbus aircraft, which spans the European continent and other countries, is a clear example. Airbus has plants in China, France, Germany, Spain and the United States. Yet interfirm relations are strong. Quadrant 3 shows the third type of cluster, characterized by a high spatial concentration of firms but weak interfirm links where knowledge is exchanged more formally. Synergy in this case can be encouraged through various national policies, for example by bringing together firms that may benefit from fis-

[6] Innovation clusters are characterized by a high spatial concentration of firms, knowledge institutions such as universities and other types of innovation intermediaries.

cal incentives to colocate their research and development activities in a science park. This type of incentive gave rise to the strong electronic games industry in Montreal. Over time, interactions between individuals often lead to more organized links between firms in these clusters. Quadrant 4 is not considered to be a type of cluster because it lacks both geographical and organizational proximity.

The measured impact of clusters depends on the type of cluster being considered as well as the precision and level of aggregation of the indicators used to gauge this impact (Beaudry and Schiffauerova 2009). Performance indicators commonly found in the literature include the propensity to innovate and the number of innovations; the number of patents and their citation-based quality or value; and employment and revenue growth. There is a need to better define and assess these indicators. They are measured either at the firm level, to assess the performance of firms within clusters compared to more isolated firms, or at the cluster level, to examine the overall performance of the organizations therein. Rarely are both levels examined jointly to assess the extent to which the arrangement is a win-win for the firm and the cluster. This is something that the ecosystem framework enables.

Although some view geographical proximity as an advantage in facilitating collaboration, it is neither sufficient nor necessary for successful collaboration. Collaboration can be coordinated at a distance through *temporary proximity* (Torre 2008), for instance short trips of a few days to a few weeks or months for the team to meet face to face. Researchers have also come to recognize the importance of cognitive and social proximity for the success of ecosystems. *Cognitive proximity* measures the degree to which individuals or organizations share a common knowledge base. *Social proximity* refers to how socially close individuals are, or how well they know each other and interact. Several researchers argue that cognitive proximity is the principal cause of tacit knowledge spillovers from one firm to another (Breschi and Lissoni 2001). This can happen regardless of whether the firms are colocated or geographically dispersed within a community that shares a common knowledge base. For more efficient knowledge transmission (Agrawal, Kapur and McHale 2008), however, a degree of social proximity is also required, that is, strong trust relations between actors based on friendship, kinship and experience (Boschma 2005).

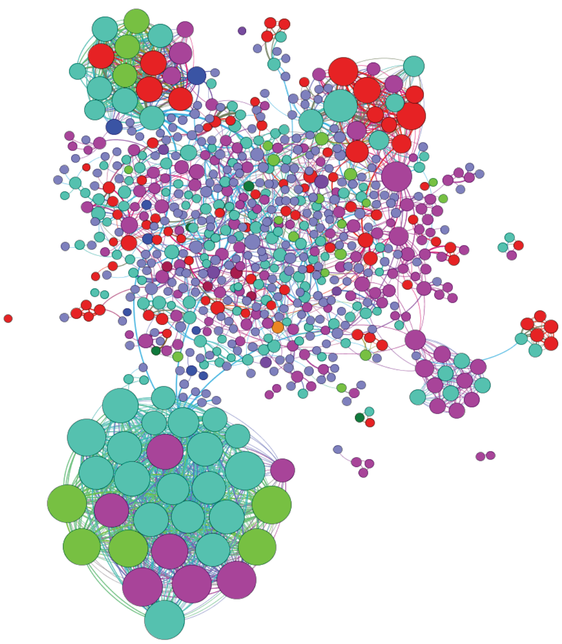
Coherent and efficient coordination of innovation can take place at the subnational level, such as in the provinces, territories or smaller regions in Canada. Yet national and international links to other organizations are often beneficial to the innovation process (Walshok, Shapiro and Owens 2014). To fully understand innovation ecosystems, we must consider another layer of links and relationships beyond geographically bound clusters. The literature on knowledge networks provides this second building block.

Knowledge networks

The literature on innovation ecosystems often refers to the networking aspects of the relationships (the links of the networks) between actors (the nodes of the networks), which are not necessarily geographically bound as is often assumed in the cluster literature (figure 1). Marco Iansiti and Roy Levien describe ecosystems as being “formed of large, loosely connected networks of entities” (2004 35). Erik Den Hartigh, Michiel

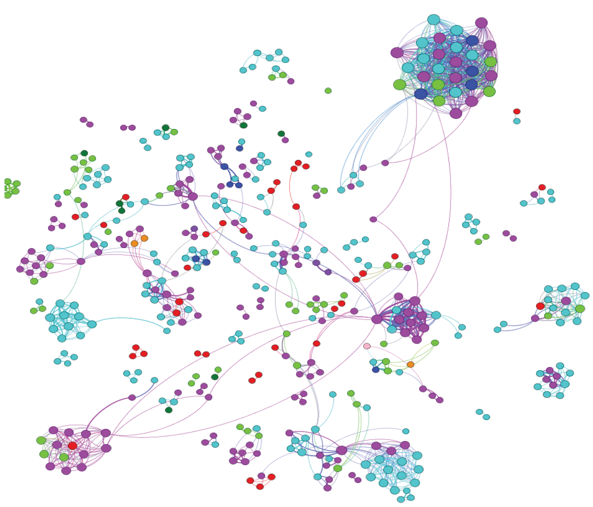
Tol and Wouter Visscher describe them as consisting of "a network of actors around a core technology, who depend on each other for their success and survival" (2006, 2). The geographical proximity of actors is rarely considered in this literature.

Figure 1. Dense knowledge network



Source: Authors' illustration.

Figure 2. Sparse knowledge network



Source: Authors' illustration.

Organizations, units within organizations and individuals that occupy a key network position are generally more productive and innovative.[7] This can be a function of how highly connected (or central) these individuals and organizations are within the network and whether their collaborators are interconnected (form a close-knit community). For example, firms that collaborate with multiple university teams, collaborate with both suppliers and clients to codevelop technologies, and use technologies from several providers are considered technology integrators. They occupy central positions in their respective networks.

In highly interconnected or dense networks, knowledge and information travels relatively fast. This facilitates knowledge sharing. Basic science networks are predominantly highly dense networks (Wagner 2018), where access to the opposite side of the networks requires only a few handshakes. The individuals and organizations that link different parts of a network that would otherwise be disjointed (see nodes highlighted in figure 1), often bridge the gaps between communities, sectors, disciplines or industries. Burt refers to such gaps as structural holes (1992). The firms and researchers that

[7] See, for example, Gilsing et al. (2008); Schiffauerova and Beaudry (2012); and Schilling and Phelps (2007).

first combined biology, computer science and information engineering to create the bioinformatics interdisciplinary field occupied such intermediary positions in their network (Freeman 1977). Since innovation often stems from the new combination of existing knowledge, these intermediaries play an important role.

At the other end of the spectrum in terms of network structure are less dense or sparser networks. An example is shown in figure 2. Such networks are characteristic of applied science fields and most innovation networks. As a technology matures, moves toward market application and transforms into product innovation, firms require fewer collaborators with which they have strong relationships, and they distance themselves from governments and universities. That is not say that they completely isolate themselves from centres of science and knowledge generation, but the latter are no longer in the immediate network surroundings of the firm for the technology in question.

As such, innovation ecosystems and the superclusters are networks built to integrate different strong science communities, well-integrated sectors and supply chains, as well as other organizations and firms interested in the use of common key technologies. We therefore expect to find that the networks of members and researchers within the superclusters are relatively sparse, with dense clusters of nodes united by structural holes occupied by innovative individuals or organizations.

There is an ongoing debate in the literature about which type of knowledge network, dense or sparse, is more conducive to innovation. Both have their strengths and weaknesses. A dense network can facilitate close collaboration but may be impervious to outside innovation. A sparse network, with its structural holes, can contribute to the creative process by combining ideas from diverse sectors. But it may lack the capacity for intensive collaboration. Both models can be complementary within a sparser network structure, however. Pockets of dense, closely linked communities connected by one or more structural holes can create strong ties among members and intersectoral exchanges that are beneficial to knowledge exchange, idea generation and exploration (Wang 2016), as well as innovation (Rost 2011).

The literature on knowledge networks is neither abundant nor conclusive regarding their role in generating innovation in the case of the specific disruptive technologies[8] at the heart of the Innovation Superclusters Initiative. It remains to be seen whether the players developing these technologies will be able to successfully establish strong links with organizations using other technologies or with other sectors within the superclusters. Will the individuals and organizations expected to occupy structural holes between technologies, and between new and more traditional sectors, foster the recombination of knowledge necessary to accelerate innovation?

Beyond their structure, the strength of network links is also important (Baum, Cowan and Jonard 2014). Informal relationships and collaborations, such as social ties, partici-

[8] These disruptive technologies include AI, advanced manufacturing, protein technologies and augmented reality.

pation in associations and their events, trade fairs and international community gatherings, and even knowledge trading, play a crucial role in catalyzing knowledge within innovation ecosystems as well as in open innovation (Henkel, Schöberl and Alexy 2014; West et al., 2014). These informal ties, which are implicit in the cluster literature and are formally acknowledged but considered difficult to measure in the network literature, are what make innovation ecosystems work. This is particularly important in the case of disruptive technologies, where problem solving requires more extensive collaboration and a certain degree of openness. As AnnaLee Saxenian pointed out, Silicon Valley engineers who once worked together remained in contact after moving firms and often interacted formally and informally to exchange information and solve technological problems (1994). Social, organizational and cognitive proximity between individuals was crucial to the rise and maintenance of the Silicon Valley advantage. This collaboration culture blurred the boundaries of firms.

Collaboration

If innovation clusters and knowledge networks are the building blocks of innovation ecosystems, collaboration is the glue that brings both concepts together. Collaboration within and between organizations or sectors acts as a catalyst. It accelerates the sharing of information, skills and resources; improves the generation, valuation and validation of ideas; increases the capacity of organizations to innovate; and spans disciplines, organizations, sectors and users.[9] Firms that collaborate with their clients, suppliers and universities are generally more innovative. Firms are often located close to their clients or to their suppliers, but that does not necessarily mean they collaborate with them. Collaboration can occur across different types of proximity, be it geographical, cognitive or social, and at different stages of the innovation value chain, such as at the knowledge, ideas or project stage.

The challenges posed by discontinuous and potentially disruptive technologies will demand broader intersectoral and interdisciplinary collaboration from firms seeking to benefit from such changes. The speed at which these technologies impose themselves on the market will force the codevelopment of new innovation practices, policies and regulation involving all stakeholders. It is therefore imperative to rethink the roles of and collaborative relationships between policy-makers, decision-makers, experts, academics and final users.

For instance, universities and other contributors to science and technology are expected to help develop new technologies and commercialize the fruits of their research through mechanisms such as technology transfers, licensing and the creation of spinoffs, or with the help of the private sector (Breznitz and Feldman 2012). In particular, research collaboration between the private and public sectors is seen as essential, which is why university-industry links have become an integral part of the university funding landscape (Goldfarb 2008). The nature, process and value of the resulting innovations are well documented (OECD 2015). Far from being detrimental to science, university-industry links lead to research that has more impact (Lebeau et al. 2008). This raises the question of Canada's poor performance in

9 For more on the benefits of collaboration, see Koen, Bertels and Kleinschmidt (2014); Cuijpers, Guenter and Hussinger (2011); and Dahlander and Gann (2010).

this regard. University-industry links that bridge the gaps between knowledge, technology and innovation[10] were expected to be the key to improving Canada's innovation performance. The results have been disappointing.

INNOVATION ECOSYSTEMS AS A METAPHOR

The concept of innovation ecosystems draws broadly on the literature and research investigating the benefits of innovation clusters, various types of proximities, knowledge networks and collaboration. Because innovation clusters and knowledge networks are known to have a positive influence on innovation, we expect that organizations involved in strong innovation ecosystems should also be more innovative (Adner 2006).

The economist Michael Rothschild was the first to use the term "ecosystem" as a metaphor in the economics and management of innovation literature. His 1990 book, *Bionomics: Economy as Ecosystem,* inspired James Moore to describe firms and their networks as business ecosystems. "In a business ecosystem, companies coevolve capabilities around a new innovation: they work cooperatively and competitively to support new products, satisfy customer needs, and eventually incorporate the next round of innovation" (Moore 1993, 76). By transposing the notion of the biological ecosystem to the economy, he also redefined the economic system as an ecosystem where organizations and consumers represent living organisms intertwined in mutually dependent relationships (Moore 1996).[11]

Business ecosystems include small and large businesses, universities, research centres and public sector organizations and tend to position themselves around a leading company (Peltoniemi 2005). Such ecosystems may include a company's competitors as well as its customers, whose behaviour is likely to influence the company's performance. The diversity of the actors involved is partly attributable to the digital transformation of several industrial sectors. It also reflects the convergence of a variety of technologies and industries, such as data science in precision medicine, industrial Internet of things in aerospace, 3D printing in health, and AI in mobility services. By coevolving their skills, the various organizations that constitute the business ecosystem create value for their customers (Moore 1996). The term "ecosystem" emphasizes the crucial role of networking and the participation of varied actors in the innovation process (Smorodinskaya et al. 2017).

The concept of business ecosystem focuses on the firm and its network. Some researchers built on this concept as they examined the way firms were using external as well as internal resources in the innovation process. This led to the notion of innovation ecosystems and of open innovation ecosystems (Adner 2006; Rohrbeck, Hölzle and Gemünden 2009). Open innovation provides key insights on how innovation ecosystems work and perform.

[10] University-industry relations are discussed in more detail in Perkmann et al. (2013); and Baycan and Stough (2013).

[11] Iansiti and Levien also picked up on this idea in their work, "Like species in biological systems, firms interact in complex ways, and the health and performance of each firm are dependent on the health and performance of the whole. Firms and species are therefore simultaneously influenced by their internal capabilities and by their complex interactions with the rest of the ecosystem" (2004, 35).

Open innovation

Collaboration, cooperation and open innovation are of paramount importance to well-functioning ecosystems. This was implied in the cluster literature and formally measured in the literature on knowledge networks. Many firms had already adopted at least some forms of open innovation before the concept was first described by Henry Chesbrough in his 2003 book, *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Indeed, since the 1970s, research and development is no longer performed entirely within the firm. The locus of innovation has migrated out of a company and into the value network to which it belongs (Brandenburger and Nalebuff 1996). The value network has replaced the concept of value chain because products and services have become dematerialized and the value chain no longer has a purely physical dimension. In value networks, value is cocreated by a combination of players in the network. This compels a degree of open innovation, defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation respectively" (Chesbrough, Vanhaverbeke and West 2006).

Open innovation encompasses three main groups of activities: inbound activities, outbound activities and a mixture of the two generally referred to as coupled activities.[12] An organization undertakes *inbound activities* when it mobilizes external resources and knowledge acquired, for example, through licensing or crowd-sourcing. Firms with greater market knowledge may acquire new innovations in order to sell them to other organizations. *Outbound activities* refer to the external use and exploitation of internal knowledge. Such activities consist of transferring knowledge and the results of internal research and development to external partners for them to commercialize. For example, a firm could benefit from selling or granting access to some of its intellectual property to a company that has a business model better suited to the commercialization of that technology. A company may also decide to externalize the commercialization of internal knowledge when the latter does not match its strategic objectives. This can generate revenues from technologies, goods or services that would otherwise have remained on the shelf. C*oupled activities* are a combination of the first two, where sharing complementary resources among partners can lead to critical innovation.

As the previous paragraph suggests, open innovation does not necessarily involve collaboration. A firm may, for instance, find an external path to market for a technology that it does not want or need to commercialize itself. Conversely, firms may contract out research and development activities or obtain a licence for patented technologies without signing a collaborative agreement.

With open innovation, innovation is no longer confined to the boundaries of a firm. It is developed at least partly outside the organization with other firms, governments or

[12] See, for example, Chiaroni, Chiesa and Frattini (2011); Huizingh (2011); Rohrbeck, Hölzle and Gemünden (2009); Vanhaverbeke et al. (2017); and Gassman and Enkel (2004).

universities. Many factors contributed to this change in the way organizations innovate, among them the increasing complexity and cost of research and development, and accelerated technological change. Opening to other organizations allows firms to break down silos, acquire more resources, reduce risk and share knowledge and resources.[13] Linear and closed innovation processes, as well as traditional business models, have evolved toward more open and interactive structures, where informal links adjoin formal relationships (Cohendet and Simon 2017; Autio and Thomas 2014). The concept of open innovation perfectly complements the literature on clusters and networks in characterizing the links between different types of organizations within innovation ecosystems.

Ecosystem diversity

Open innovation underscores the importance of collaboration between diverse stakeholders, each of whom contributes to innovation in its own way. Within innovation ecosystems, the focus of analysis is on the interactions between interdependent actors whose objective is to create and market innovations benefiting the end user. While business ecosystem studies concentrate on the firm and its environment, innovation ecosystem studies focus on innovation and the constellation of actors that support it.

An organization can be involved in various ecosystems (knowledge, innovation or business ecosystems) and play a different role in each (Valkokari 2015). Similarly, while the same set of diverse actors from different sectors, businesses, universities or government institutions may populate business and innovation ecosystems, their role and importance differ from one ecosystem to another. A firm can be the leader of an ecosystem, but leadership can also fall to another type of organization, such as a university or a government entity. Relationships are not strictly hierarchical among ecosystem members but rather collaborative. This makes network literature useful when studying these interorganization links.

The core of business ecosystems consists of firms, suppliers, consumers and distributors. Other organizations are only weakly involved. In contrast, innovation ecosystems are characterized by the importance of research institutions, local intermediaries and policy-makers. They include participants from outside the traditional value chain (Valkokari 2015). These can be customers, universities that provide science and technology, regulators, innovation coordinators or intermediaries, and firms that coevolve with the ecosystem, often in symbiotic relationships (Mazzucato and Robinson 2017). These participants are often geographically concentrated, which is why the cluster literature remains relevant in studying innovation ecosystems.

Silicon Valley clearly functions as an innovation ecosystem. While governments have tried to imitate or reproduce Silicon Valley, few have succeeded by adopting a simple

[13] Research intermediaries in Quebec and Canada are facilitating open innovation among firms, universities and research centres. Various public policies led to the creation of these research intermediaries, whose main mission is to induce collaborations in their economic sector among small and medium-sized enterprises, large firms, and universities. The pioneer of the current model of research intermediary, the Consortium for Research and Innovation in Aerospace in Quebec (CRIAQ), was founded in 2002. It has now expanded to the rest of Canada as the Consortium for Aerospace Research and Innovation Canada (CARIC).

cluster approach. With the superclusters initiative, deliberately anchored in Canada's technological, sectoral and economic strengths, Ottawa is experimenting with something different. It is trying to encourage intersectoral collaboration, which does not come naturally to most firms.[14]

INNOVATION ECOSYSTEMS IN PRACTICE — THE CANADIAN SUPERCLUSTERS

According to the government's program overview, the Innovation Superclusters Initiative is meant to encourage the establishment of "large-scale industry partnerships, supported by other innovation ecosystems players." Aspiring superclusters were asked "to work together on ambitious market-driven proposals to supercharge their regional innovation ecosystems, enhancing the growth and competitiveness of participating firms and maximizing economic benefits, including good, well-paying jobs and prosperity for Canada" (Canada 2017a). A key objective is to promote widespread wealth creation through the adoption of new and potentially disruptive technologies within innovation ecosystems, particularly by small and medium-sized enterprises.

This bold approach aims to reverse Canada's deteriorating innovation performance, accelerate the adoption by Canadian firms of several key transformative technologies and foster a strong entrepreneurial or start-up culture. The government hopes that by facilitating the involvement of all stakeholders in the superclusters, bottlenecks such as the snakes-and-ladders game between regulation and innovation and other difficulties in translating science and technology into successful products can be overcome. Under the initiative, universities, government laboratories, innovation intermediaries and firms of all sizes are having to work together to develop a functional governance structure for these very large innovation ecosystems. This is expected to help flag problems along the innovation value chain and create the climate of trust necessary for greater collaboration among different disciplines and sectors.

More generally, promoting the emergence of strong innovation ecosystems that span several sectors, even beyond those involved in the superclusters initiative, has the potential to strengthen Canada's innovation capacity and competitiveness. The literature surveyed in this article certainly hints at the potential benefits of innovation superclusters, although their true economic impact has yet to be accurately measured. Learning from the experience of the innovation superclusters and that of other innovation ecosystems is timely and crucial for the Canadian economy.

Despite their names, the five superclusters are centred on technologies rather than industrial sectors. These are detailed in box 1. While all superclusters have a strong local base, they span several regions of the country, building on numerous strong,

[14] For more about Canadian business culture, see Nicholson (2018).

Box 1: The five innovation superclusters

Ocean Supercluster
Location: Atlantic Canada
Objectives: will harness emerging technologies to strengthen Canada's ocean industries, industries like marine renewable energy, fisheries, aquaculture, oil and gas, defence, shipbuilding and transportation.
Main technologies: Digital sensors and monitoring, autonomous marine vehicles, energy generation, automation, marine biotechnology and marine engineering technologies.

AI-Powered Supply Chains Supercluster
Location: Quebec and spanning the Quebec-Windsor corridor
Objectives: will bring the retail, manufacturing, transportation, infrastructure and information and communications technology sectors together to build intelligent supply chains through artificial intelligence and robotics.
Main technologies: Artificial intelligence and supply chain technology.

Next Generation Manufacturing Supercluster
Location: Ontario
Objectives: will build next-generation manufacturing capabilities, incorporating technologies like advanced robotics and 3D printing.
Main technologies: Internet of things, machine learning, cybersecurity and additive manufacturing such as 3D printing.

Protein Industries Supercluster
Location: Prairies
Objectives: will use plant genomics and novel processing technology to increase the value of key Canadian crops, such as canola, wheat and pulses that are coveted in high-growth foreign markets, such as China and India, as well as to satisfy growing market demand in North America and Europe for plant-based meat alternatives and new food products.
Main technologies: Agri-food enabling technologies, including genomics, processing and information technology.

Digital Technology Supercluster
Location: British Columbia
Objectives: will use bigger, better datasets and cutting-edge applications of augmented reality, cloud computing and machine learning to improve service delivery in the natural resources, precision health and manufacturing sectors.
Main technologies: Virtual, mixed and augmented reality, data collection and analytics, and quantum computing.

Source: ISED (n.d.) https://www.ic.gc.ca/eic/site/093.nsf/eng/00008.html

local technology hubs. The concept of innovation ecosystem is the appropriate framework to study the supercluster initiative but, as we have shown, it is a concept that encompasses several others. No single strand of the literature can fully describe the ways in which the superclusters initiative can help reverse Canada's downward innovation spiral, nor how it can become a successful Canadian innovation in and of itself. The lens needed to understand how the superclusters operate, to measure whether they achieve their goals and to evaluate their performance does not yet exist. More research is needed to equip organizational actors with a comprehensive conceptual framework and the appropriate indicators and decision-making tools to bring about the necessary transformations.[15]

[15] The conceptual framework is needed to develop the necessary indicators and decision-making tools that in turn will lead to effective action and policies.

Key performance indicators: Measuring what matters

The initial program guide provided to applicants wishing to take part in the superclusters initiative included four clearly stated objectives and a list of seven key performance indicators to measure expected outcomes over the life of the program. These are detailed in box 2. This signalled the government's intention to monitor the impact of its investment. Although they broadly cover the main goals of the initiative, the initial key performance indicators consist mainly of generic indicators that, in our view, overemphasize basic metrics such as the number of collaborative projects, participating companies and organizations, and the number of jobs created in small and medium-sized enterprises. These provide a good starting point to measure results, but are too simplistic to gauge the full impact of the superclusters initiative on innovation and collaboration. Since the initiative was launched, Innovation, Science and Economic Development Canada has been consulting with experts and working with members of the five superclusters to develop a more detailed and precise set of indicators. Some of these are included in box 3.[16]

Box 2: Stated objectives and key performance indicators for innovation superclusters

Objectives:

- Build a shared competitive advantage for their cluster that attracts cutting-edge research, investment and talent by addressing gaps, aligning strengths, enhancing attributes and positioning it as a world-leading innovation hotbed.
- Increase business expenditures on research and development and advance a range of business-led innovation and technology leadership activities that will address important industrial challenges, and boost productivity, performance and competitiveness for Canada's sectors of economic strength.
- Generate new companies, and commercialize new products, processes and services that position firms to scale, connect to global value chains, transition to high-value activities and become global market leaders.
- Foster a critical mass of growth-oriented firms, and strengthen collaborations between private, academic and public sector organizations pursuing private sector led innovation and commercial opportunities to enhance the cluster's pool of resources, capabilities and knowledge.

Initial key performance indicators:

1. Number of funded or launched collaborative projects that involve a minimum of two private sector organizations and one academic institution
2. Dollar value of investment committed by private sector entity members to technology projects initiated, completed or undertaken
3. Number of companies participating in the initiative
4. Increase in participating organizations for each funded entity
5. Number of products or processes developed, improved and/or commercialized by participants
6. Rate of employment growth for small- and medium-sized enterprises participating in the initiative, per funded entity and
7. Extent to which amplifying activities are aligned with each cluster's ecosystem needs.

Sources: ISED (n.d.) https://www.ic.gc.ca/eic/site/093.nsf/eng/home and https://www.ic.gc.ca/eic/site/093.nsf/eng/00003.html#toc-05.09.

[16] At the time of writing, Innovation, Science and Economic Development Canada (ISED) was still refining its methodology and working with experts to ensure that the indicators used to measure the progress of the superclusters are based on best practices and new research. The list included in box 3 is a representative sample of the indicators selected so far. We are grateful to the organization for having shared this list with us.

Box 3: Select list of updated key performance indicators for innovation superclusters

Private sector invests in technology research, development, demonstration and commercialization

1. Dollar value of business enterprise research and development
2. Dollar value of investment in research, development, demonstration and commercialization

Private, academic and public sector organizations collaborate

3. Number of collaborative projects
4. Percentage of companies conducting collaborative research and development
5. Number of member organizations for each funded entity
6. Number of professionals, including science and technology professionals, participating in Innovation Supercluster Initiative activities

New or improved products or processes are developed and commercialized

7. Number of patents or copyrights
8. Number of products, processes or services developed, improved or commercialized

Innovation ecosystems contribute to wealth creation

9. Increase in contributions to gross domestic product by small, medium-sized and large enterprises
10. Proportion of participating small and medium-sized enterprises that export goods and services

Innovation ecosystems grow

11. Rate of employment growth for participating small and medium-sized enterprises
12. Number of jobs created
13. Number of new firms created
14. Number of high-growth firms that receive funding from the initiative
15. Number of high-growth firms as a result of funding

Source: ISED (n.d.)

The first group of key performance indicators in box 3 underline the need to boost investment in industrial research and development. Business enterprise research and development has been chronically below par in this country. Canada has been falling behind other OECD countries on this indicator for more than a decade (CCA 2018). The revised indicators are an improvement on the initial indicators proposed by recognizing the importance of investing in demonstration and commercialization activities, which often become increasingly costly as the technology moves toward the market. It will be important to track whether and where these investments take place.

More generally, the updated performance indicators are directly aligned with the government's strategy to advance business-led innovation and technology leadership activities, and to boost productivity, performance and competitiveness. The dollar value of such investments provides a strong indication of business commitment to innovate, but we also need to be able to monitor how the superclusters go about implementing the necessary changes. Boosting a firm's productivity, performance and competitiveness requires putting together the best teams and mobilizing the right set of resources to foster innovation. The former requirement can be gauged in part by the number of science and technology professionals participating in supercluster activities, the number of jobs created and the rate of employment growth in small and medium-sized enterprises. Whether the right set of resources has been assembled can be measured by the outcomes: the number of products and processes developed, improved and commercialized.

The third set of indicators also includes the number of patents or copyrights. This is an important addition to the list because, in some cases, the technologies being promoted by the superclusters are at a relatively embryonic stage of development. It is likely that some of the most ambitious projects will only reach a relatively early stage of technology maturity by the end of the five-year program. Having an interim indicator, such as the number of patents and copyrights, will provide an idea of the innovation potential of the supercluster.

Translating investment in research and development into innovation is a necessary step to improving economic growth. Yet the actual economic impact of these activities in terms of increases in revenue, market share or exports was absent from the government's initial list of indicators, although such indicators are included in the strategic plans of most superclusters. They are now on the government's list, focusing on two elements: increases in contributions to gross domestic product and in the share of small and medium-sized enterprises that export goods or services. This definition of wealth creation, however, is considerably narrower than the aggregate economic, social and environmental benefits contemplated by the Council of Canadian Academies in its 2018 report. Canadians expect government investments in innovation to lead to improved quality of life, pollution reduction, health improvements and poverty reduction. Ultimately, these are the types of outcomes that we should be measuring. But it is notoriously difficult to do so.

The idea behind the second set of key performance indicators is that more collaboration between private, academic and public sector organizations will improve the country's commercialization performance. The extent of university-industry collaboration is used as an input indicator in the innovation literature and by the World Economic Forum.[17] But simply counting the number of collaborative projects will not be conducive to large-scale collaboration and may even be counterproductive as it encourages a multiplicity of small projects. Having an excessive number of small projects or larger projects broken down into smaller ones to meet performance indicator requirements will make it more difficult to coordinate and to measure the overall impact. These biases may be partially counterbalanced by also counting the number of member organizations involved in each project, although this is more suitable for larger or more important projects. And, while these metrics may be indicators of scale and potential reach, they fail to convey any information about the quality of the links and relationships within the ecosystem or how productive they are in terms of outcomes. Indicators aimed at characterizing these relationships should be developed to monitor progress over the course of the initiative. Finding ways to measure the benefits of collaboration would be a further challenge, but it would help offset potential biases linked to simple project counts.

[17] See, for example, Mercan and Goktas (2011); and Schwab (2019). Both references use the same indicator of university-industry collaboration based on a Likert scale of its intensity in the country. This type of indicator is easily adaptable to the scale of the innovation ecosystem and complementary to the other indicators proposed. Other scholars have also counted the number of collaborations of various forms (see Brusoni and Prencipe 2013; Deshpande et al., 2019).

The expanded set of indicators emphasizes innovation ecosystems' growth, monitoring employment growth in participating small and medium-sized enterprises and the number of new jobs created overall. Tracking the number of new firms created and the number of high-growth firms involved in the supercluster is consistent with the scale-up objective. Some caution is warranted, however. Beyond the desired spinoffs, start-ups and gazelles alluded to in the government's objectives, many of the high-growth firms that will be added to the count likely already belong to existing sectors. Many of the so-called new employees come from somewhere else. Although this is not a zero-sum game, employees who leave their current employment to move to small and medium-sized firms involved in the superclusters will deplete firms, sectors, regions and ecosystems elsewhere.

The inevitable but beneficial workforce mobility involved in the innovation process should be taken into account. For example, when an aerospace firm is developing a new aircraft, its workforce is likely to decrease if demand is declining for its older aircraft models. Yet this is often the most innovative period for the company. Simply counting the number of employees, or employment growth, will not reflect the firm's innovative capacity embodied in its employees. We suggest that measures of the quality and innovative capacity of human capital in relation to the stage of development of the technology be added to the indicator list. Existing innovation surveys already gather information on the number of employees with technical, science and engineering degrees, PhDs, or those devoted to research and development or tasks related to commercialization. A culture that encourages employees to innovate is an important contributor to the innovation process. Mercan and Goktas (2011) used elements of the Global Innovation Index developed by the World Economic Forum and INSEAD, a graduate business school (Schwab 2019), to measure innovation culture. With the power of big data analytics at our fingertips, we can go one step further and account for the experience employees have had in past projects and their involvement in successful innovations.

Given the government's focus on technologies rather than sectors in designing the superclusters program, an important missing performance indicator relates to the transfer and adoption of technologies by firms and organizations in sectors other than those that produce them. As shown in box 1, there is a particular focus on promoting the adoption of digital technologies and AI by Canadian firms. How transformative these technologies will be for the firms that adopt them will need to be assessed. Successful adoption is likely to occur through informal relationships and the sharing of tacit knowledge, which are difficult to measure. It is the key to greater competitive advantage and wealth creation for the adopting firms and organizations.

The contribution of innovation ecosystems to economic growth, competitiveness and wealth creation cannot simply be measured in terms of the number of new products or processes or increases in exports, productivity and gross domestic product. Some of the superclusters such as NGen, the supercluster focused on next-generation manufacturing, have adopted more extensive performance indicators.

Yet their overall approach is the same as that of the government.[18] Such indicators may be easier to quantify, but they are at best proxies for innovation and its impact. Ultimately, the government and the superclusters will need to develop more sophisticated indicators to truly measure the potential and the impact of innovation ecosystems. This will enable stakeholders to adapt innovation practices and policies to provide a win-win environment for the ecosystems and their constituent organizations.

Supporting effective innovation ecosystems: Addressing knowledge gaps

The Innovation Supercluster Initiative provides a unique opportunity to advance knowledge about superclusters beyond a few simple metrics aimed at demonstrating value for the public investment. Gaining a better understanding of supercluster dynamics would benefit not only policy-makers but all stakeholders. Indeed, the supercluster initiative should be viewed as somewhat of a Canadian experiment. Identifying the factors that facilitate the emergence and success of these superclusters and other ecosystems will help policy-makers better design and fine-tune innovation policies and programs. The timing is certainly propitious. Having mobilized their communities around specific technologies or sectors, groups that applied but were not chosen to become superclusters in 2017 have tried to maintain momentum by setting up more formal governance structures and accessing various government programs. Identifying and measuring the commonalities and divergences of other innovation ecosystems as they emerge would help governments target the right policies to foster their success.

We urgently need to design and test new metrics adapted to the reality of innovation ecosystems. The tools currently at our disposal provide measurements that are at best proxies for true innovation potential. We need indicators that accurately reflect the complex dynamics of collaborating across provinces, sectors and organizations on the digital transformation of traditional sectors while making the most of the discontinuous and potentially disruptive technologies.

There is still much we need to learn. For instance, the way in which innovation ecosystems emerge, adapt to paradigm shifts brought about by new disruptive technologies, and bridge the gap between science and technology and the commercialization of innovation is still poorly understood. Ecosystems are not static. They evolve as innovations develop. It is therefore important to identify the characteristics and similarities of different types of innovation ecosystems at different points in their life cycle. This includes their contribution to and impact on the generation and conversion of ideas and on the commercialization and implementation of innovation.

We do not yet know how to assess the different governance structures that span informal and formal relationships within innovation ecosystems. To ensure that the

[18] A notable exception is the Protein Industry Canada Supercluster that aims to address regulatory barriers to innovation and help develop "a regulatory system that supports and encourages innovation across the value chain while ensuring food, feed and environmental safety". This key performance indicator could have a transformative impact.

superclusters and other innovation ecosystems operate efficiently requires a deeper understanding of the organizations and individuals at the core of these networks and the specific roles they play as the convenors or facilitators of their ecosystems. There are numerous examples of successful governance structures, shared intellectual property and trust-based collaborative groups in Canada. But they are often well-guarded secrets. The Consortium de recherche et d'innovation en aérospatiale au Québec (CRIAQ) is one example. Under the CRIAQ contract between universities and aerospace firms, all prior intellectual property is declared and new intellectual property is shared among the industrial partners, without preventing academics from conducting further research on the subject. This model has existed for several years and has contributed to enhancing Quebec's aerospace innovation performance.

A crucial task is to accurately gauge the win-win conditions for both individual organizations and ecosystems. It would be counterproductive to adopt key performance indicators at the level of the individual organization, whether it is a firm, university, government organization or innovation intermediary, that are incompatible with those at the level of the innovation ecosystem. A minimum degree of coherence is necessary to ensure the success of well-organized innovation ecosystems. That raises questions. How much self-organization or self-governance do ecosystem members require as opposed to, or in addition to, a more top-down approach? How loose or formalized should the decision-making process be within the ecosystem? How should its convenors oversee decision-making to foster innovation? In the case of the superclusters, a strong sectoral governance structure may dominate and impose itself, but it may not produce the expected innovation boost.

Developing new and validated key performance indicators for innovation ecosystems is one of the main goals of the Partnership for the Organisation of Innovation and New Technologies. Although the scope of our project is broader than measuring the impact of the superclusters, our research community has much to learn from innovation ecosystem dynamics and the success factors underlying their performance. The superclusters initiative provides fertile ground to test new ways to assess industrial and ecosystem performance and to compare those results with more traditional metrics such as those mentioned in boxes 2 and 3. It is encouraging that the department of Innovation, Science and Economic Development wishes to remain at the forefront of new research and is open to developing news ways to measure the impact of its supercluster program. It has been a partner of our organization since the beginning and is codeveloping with us these new indicators of ecosystem innovation and performance.

CHALLENGES FOR INNOVATION ECOSYSTEMS AND THE SUPERCLUSTERS

In Canada, we are still looking for the recipe to scale up firms. How to scale up ecosystems is an even greater challenge. We know, for instance, that stakeholders take part in ecosystems because they see an opportunity to resolve issues and develop market opportunities. Firms scale up when their market expands locally or internationally.

Ecosystems should help in that regard. However, multiorganization collaboration requires the integration of working practices and processes. This can be challenging, especially when multiple organizations from multiple sectors are involved. But aligning scaling up with multiorganization or sectoral collaboration is precisely where the potential advantage of innovation ecosystems and superclusters lies.

A related question to be investigated is whether innovation ecosystems are agile enough to provide an alternative to the need for firms to scale up to succeed. Organizations and ecosystems are increasingly seeking to coordinate a variety of activities that were formerly scattered across diverse entities focused on different technologies. They are doing this not only to accelerate the innovation trajectory toward commercialization but also to overcome the cost pressures, technological complexity and social acceptability issues that are making innovation projects more complex. Complexity is forcing firms to collaborate. More research is needed to develop and implement new practices, platforms, roles and functions to operationalize and govern ecosystems and their member firms as they scale up. This is particularly important when multiple sectors are involved, as is the case for most superclusters.

As traditional economic sectors (aerospace and manufacturing in general) look to benefit from advances in big data analytics and AI technologies, it is important to document and understand how ecosystems successfully evolve in response to the challenges brought about by these technologies. Gaining better knowledge of these new networks and collaborative spaces will contribute to the development of effective public policies and industry practices that are conducive to the sustainability of ecosystems.

In this context, it is particularly important to understand the "modularity of technological artifacts" within innovation ecosystems (Beltagui, Rosli and Candi 2020). This term refers to the degree to which the components of a technology can be separated and recombined. At the heart of the supercluster initiative is the government's wish for a wide-scale digital transformation of the Canadian industrial fabric. Adoption of new digital modules within an industry or sector, such as manufacturing or health care, will disrupt traditional innovation processes and constitute a paradigm shift in all the sectors that will be affected. For instance, big data analytics is transforming the health care ecosystem by recombining specific technological and medical modules (such as AI, genomics and pharmacology), further personalizing medical treatment and fostering the emergence a new digital health ecosystem. In the manufacturing sector, 3D printing will revolutionize and shorten the product development process, displacing some of the traditional ways used to produce and assemble complex objects. The manufacturing sector will need to evolve to benefit from these new technologies.

The integration of new technologies in more traditional sectors may require the use of specific creativity methods, such as design thinking, to explore how to best combine knowledge from unrelated disciplines and sectors.[19] This will likely involve other

[19] See Cohendet and Simon (2015); Leidtka and Ogilvie (2011); and Le Masson, Weil and Hatchuel (2010).

stakeholders, such as users and non-experts, which adds a level of complexity. Organizations must come up with new configurations to support the development of creative ideas through both internal and external initiatives (Cohendet, Grandadam and Simon 2010). Identifying the instigators of these transformations will help trigger change in laggard sectors, clusters or ecosystems.

To fully benefit from their innovation ecosystems, individual firms will also need to adopt more open and agile business models adapted to constant ecosystem evolution (Attour and Burger-Helmchen 2014). Analyzing how sectors that have successfully adopted these advanced technologies have managed the transition would provide invaluable knowledge for other sectors and ecosystems about to experience similar transformations. Worldwide, efforts are being deployed to implement industry 4.0 (the adoption of digital technologies by manufacturing), smart cities, self-driving cars, personalized medicine and smart electric grids. What these innovations have in common is that they combine knowledge and technologies from a variety of sectors or disciplines. Their impact is also cross-cutting. For instance, industry 4.0 and its underlying technologies will not only affect the manufacturing sector, but also health, transport and agri-food. Breaking down disciplinary and sectoral silos within ecosystems will be crucial. Yet public policy and regulation are still developed in sectoral silos that struggle to adapt to these disruptive technologies. Moreover, the speed at which these radical innovations enter the market leaves decision-makers in catch-up mode. This limits the innovation potential of the country.

Canadian public policy needs to change to enable the necessary transformations within firms, universities, government and society in general. New policies are needed to support the extensive combination of knowledge that spans multiple disciplines and sectors. Regulatory harmonization for sectors such as aerospace and health, which are already undergoing a vast digital transformation, and information and communication technology is urgently needed to avoid stopping transdisciplinary and cross-industry innovation in its tracks. To take one example, the extent of data collection and the stringency of the cybersecurity required for precision medicine to fully deploy suggest a clear shift is needed in the way we address regulation. One avenue that holds promise is for governments to codevelop targeted public policies and appropriate regulations with innovation intermediaries in ecosystems. Innovation support mechanisms also have to be developed in parallel with regulation. This would provide a reinforcing policy framework where regulation is no longer seen as an obstacle to the adoption of new technologies and to innovation in heavily regulated domains. [20]

CONCLUSION

At the beginning of this study, we highlighted the growing concern that Canada has failed to benefit from its strength in science and technology when it comes to

[20] Although only the protein supercluster has included this regulatory challenge in its list of key performance indicators, most superclusters have identified regulation as an important issue to address.

successfully commercializing innovation. The last two decades have seen a proliferation of university-industry funding programs. Yet these have failed to produce the desired outcomes. Something different is needed. Taking the bull by the horns, so to speak, the government initiated the Innovation Superclusters Initiative to try to reverse the downward trajectory of innovation. Starting from the premise that united we stand, the program aims to build a critical mass of partnerships between research facilities and industry that will boost innovation, productivity and competitiveness. Encouraging a more coordinated approach to ensure that transformative technologies[21] reinvigorate industrial capabilities is a bold move that is being followed closely by other countries.

Noting that the Canadian superclusters are in fact more akin to innovation ecosystems than clusters, we briefly surveyed the pertinent literature on the building blocks of innovation ecosystems. These include industrial clusters, knowledge networks, collaboration and open innovation. As none of the lenses suffices to comprehend the dynamics of innovation ecosystems, we argued that a multidisciplinary framework needs to be developed to fully understand how the superclusters operate, to measure whether their goals are achieved, and to evaluate their performance.

Furthermore, as they prepare for the adoption, diffusion and impact of discontinuous and potentially disruptive technologies such as AI and industry 4.0, Canadian firms are having to acquire a whole new set of skills that they may not have the capacity to absorb on their own. The speed at which new technologies are being developed forces all stakeholders to be involved from the beginning in well-coordinated collaborative entities, such as innovation ecosystems or superclusters. Accurately monitoring the success of innovation ecosystems and of the firms and organizations therein requires the development of new indicators. These indicators would complement the traditional key performance indicators that we automatically turn to because they are relatively easy to measure, master and understand. Herein lies the challenge. The extent of the coordination required to ensure the success of the superclusters, or to propose how to change tack in real time if need be, is unprecedented. So too is the task entailed in accurately measuring that success.

Developing, testing and providing new and more appropriate performance indicators for innovation ecosystems is the challenge our team took on in 2018. Such indicators will be invaluable. They will ensure that the cross-cutting impact and innovation potential of integrating knowledge and technology from multiple sectors and disciplines is taken into account. They will also help Canada develop effective and reinforcing innovation policies and regulatory frameworks adapted to innovation ecosystems. The results of our research will help Canadian innovation ecosystems, including the superclusters, evolve and have a long-lasting positive impact on our economy.

[21] These transformative technologies include nanotechnology, additive manufacturing, energy storage, autonomous vehicles, robotics, regenerative medicine, genomics, quantum computing, big data analytics and advanced materials. See Canada (2016).

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