The Role of Clusters in Driving Innovation

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ABSTRACT
The promise of biotechnology relies on new science that is increasingly complex and specialized and depends on sophisticated, global intellectual property rights systems. This complexity requires a more open system of knowledge sharing than previous research and development programs. Studies suggest that successful innovation requires developing clusters of institutions, businesses, and personnel. "Location, location, location," the battle cry for property realtors everywhere, is increasingly becoming the key phrase in studies of innovation dynamics and knowledge-based growth. Offering an overview of recent research on clusters in Canada, this chapter suggests that governments have an important role to play in the process of cluster formation and that ensuring a mix of "local buzz" and "global reach" is part of the recipe for success.

1. INTRODUCTION
Biotechnology has changed the discussion about research and development in agriculture and medicine. In the past, research tended to be distributed widely to meet agronomic and human health needs, but now we are seeing agglomerations forming around the research, development, and commercialization of globally mandated technologies and products. Governments view this change as an opportunity to invest in and create comparative advantages or as a threat to their competitive status and ability to access new technologies.

Theory and evidence suggest that competing, innovative companies and their related industries will tend to concentrate in a few locations. Most innovation involves a lot of learning-by-doing, which creates a barrier for imitators who want to use the innovation: they can do so only after they have gone through their own learning process. Furthermore, the cumulative impact of learning-by-doing creates stronger competition in more-innovative companies and sectors, thus erecting barriers to less-innovative actors. While basic science and inventions (usually codified through scientific journals and patents) can often be transferred at low or no marginal cost, know-how and experience are very difficult to transfer across long distances. Applied science (know-how) does spill over to others in the sector, but estimates suggest that the spillover benefits of tacit knowledge are limited to between ten and 100 miles of the epicenter. This pattern is frequently seen in the innovation corridors of Silicon Valley, Boston's Route 128, and Austin in the United States, Cambridge in England, Bangalore in India, and Saskatoon in Canada.

Grossman and Helpman[1] argue that technological spillovers limited to a specific location (due, for example, to climate or industrial structure) create an opportunity for endogenously generated comparative advantage. According to the authors, countries that engage in technology-related

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competitive activity can produce comparative advantage over time. If technological spillovers are geographically concentrated, then the initial and sequentially established conditions will affect subsequent economic growth. Grossman and Helpman further argue that, as a result, the high-technology share of GDP and exports will be greater in first movers than elsewhere. In the extreme, a country that inherits even a small technological lead could come to dominate world markets for high-technology products. A productivity differential then becomes self-sustaining.

Gilpin[2] argues that the new theories of economic growth create a new role for the state. Governments can generate growth, and numerous countries and regions have sought to do just that. By some counts, all large industrial economies, almost all major cities around the world and many smaller countries, cities, and regions have decided to invest in and nurture some form of a biotechnology cluster. There are literally hundreds of putative biotechnology clusters around the world right now.

2. BIOTECHNOLOGY, HEALTH, AND AGRICULTURE

Some 40% of the world's market economy is based upon biological products and processes—mainly food, protein and fiber production, and human health.[3] The security and the supply of food and fiber are threatened by increasing consumer demand, shrinking cultivable land, limited water, and diminishing returns on existing technologies. Further, while great strides have been made in extending and improving the quality of life, disease remains a constant daily threat in many countries. Food-supply insecurities and unchecked disease go hand in hand in many low-income developing economies, yielding a dismal, Malthusian outlook for a large portion of the world's population.

Biotechnology has potential to transform food production and health. A number of key scientific discoveries since 1970 in the fields of genomics and proteomics (for example, gene selection, gene splicing, and metabolic profiling) have opened up vast novel avenues of research, on new plants, animals, and microbes, that could have applications in medicine, agriculture, extraction, processing, and the environment. Despite some major obstacles, many scientists and policy advisors see great potential in modern, molecular-based biotechnology, especially through the new capacities to genetically modify plants and to detect and treat disease. In 2001, Daar and colleagues[4] undertook a Delphi survey of more than 30 scientists and bioethicists from around the world to identify the top ten technologies that could address a wide range of problems in the developing world. The list included eight biomedical applications: molecular technologies for affordable, simple diagnosis of infectious diseases; recombinant technologies to develop vaccines against infectious diseases; technologies for more-efficient drug and vaccine delivery systems; sequencing pathogen genomes to understand their biology and to identify new antimicrobials; female-controlled protection against sexually transmitted diseases, both with and without contraceptive effect; bioinformatics to identify drug targets and to examine pathogen-host interactions; recombinant technology to make therapeutic products such as insulin and interferon more affordable; and combinatorial chemistry for drug discovery. It also included one agricultural use: genetically modified crops with higher yields and increased nutrients that resist biotic and abiotic stresses, and an environmental application: technologies for sanitation, clean water, and bioremediation. If realized, these technologies would go a long way towards addressing the biggest food and health challenges of many developing countries.

3. LIFE-SCIENCE INNOVATION SYSTEMS

One opportunity or constraint, depending on how one looks at it, in achieving a better future is the relationship of innovation systems to life science research, development, and commercialization. In the classical model of innovation, relatively small groups of researchers (either in public laboratories or in private research groups) engaged in a mostly self-contained, linear process of research and development, a process that ultimately led to commercialization through direct or contracted production and marketing. This type of structure was exemplified by the research departments at Consolidated Edison, 3M, and Xerox, where fully dedicated research staff were given the freedom to investigate and invent new products for commercialization by the host company.

Much of the early life-science research also conformed to this model, except that it was often carried out in public laboratories (for example, the discovery of insulin by Banting and Best at the University of Toronto in 1922, the discovery of the structure of DNA for which Watson and Crick at Cambridge University received a Nobel Prize, and the creation of low-erucic acid, low glucosinolate rapeseed in Canada). While these individual efforts drew upon knowledge generated by others, most of them operated in relative isolation, with little formal or informal exchange of information during the discovery phase. This "standing on the shoulders of giants" model has generally been the basis for research efforts since the scientific and industrial revolutions of the seventeenth century. While the model may have been appropriate in earlier times, since many innovations were simply the product of inventors' ingenuity, in more recent years, many institutions, companies, and industries have used a different strategy to develop and exploit life science inventions.

Indeed, the global life-science research effort has been significantly transformed. Two specific trends have led to this change. First, this new science has become increasing complex and specialized, which makes it increasingly difficult for isolated or independent scientists to realize breakthroughs or to pursue comprehensive research programs. Instead, teams or networks of researchers pursue investigations. Second, intellectual property (IP) rights have been extended into new subject areas and new jurisdictions. The United States started the process by extending patents through the Chakrabarty case in 1980 to living, single-celled organisms; patents were then extended through a series of subsequent decisions to whole plants, animals, and many human organs (but not the whole human being). Patent granting on living matter was internationalized over the past 20 years as other countries (for example, Australia, Canada, the European Union [E.U.], and Japan) either amended their own patent laws or issued judicial decisions extending rights. This IP rights system has been extended globally through the adoption of the Agreement on Trade-Related Aspects of Intellectual Property (TRIPS) of the World Trade Organization (WTO), which, in 2006, began to require that all member states (virtually all countries) offer patents, plant breeders rights, or some other sui generis system of protection for IP embodied in living matter. Private (and public) inventors have adapted rapidly to this new regime, patenting almost all of their inventions (including the tools of discovery and the resulting products). By 2005 there were an estimated 58,000 patents relating to biotechnology tools and products in the United States, and a confusing array of rights claimed or allocated in other countries around the world. The increased role of profit seeking and the extensive use of formal IP rights mechanisms such as patents have created barriers to the free exchange of knowledge, which is now heavily scrutinized.

The specialization of science and the fragmentation of IP rights have forced scientists to collaborate and network more extensively to achieve research results (the Human Genome Project represents one type of widespread research network). Networks of institutions and researchers have evolved to handle the transfer, acquisition, and use of various forms of knowledge. Increasingly, research programs are not simply standing on others' shoulders but instead are working side-by-side through formal or informal collaborations or research networks. Sometimes these structures have grown organically; sometimes they have been actively supported and encouraged by government. Typically, they operate above the level of the company or the organization but below the global level; they are inherently regional and supraorganizational.

4. NETWORKED KNOWLEDGE

Networked knowledge exhibits three important attributes. First, it comes from a nonlinear research system, perhaps best illustrated by a chain-link model of innovation.[5] In essence, a chain-link system embeds the traditional linear development process in a series of feedback loops. At the core, new technology or product development still goes through a relatively linear process, beginning with identification of the potential market, and involving successive efforts to design, adapt and adopt a new technology or product to the market need. But, unlike the linear model, where many of these steps were taken inside a closed R&D system (either inside a single company or involving only a few, formally aligned partners), the chain-link now involves extensive search and discovery functions, with innovators often going out beyond their own system to seek out existing knowledge or to undertake or commission research to solve specific problems in the innovation process. At the root, such a system depends on the efficacy and efficiency of the relationships that link the often disparate actors together.

Second, multiple types of knowledge are involved in such a system. Malecki[6] identifies four distinct types of knowledge: "know-why," "know-what," "know-how," and "know-who." Each type of knowledge has specific features.[7] *Know-why* refers to scientific knowledge of the principles and laws of nature. It is almost always derived from research efforts undertaken in publicly funded universities and nonprofit research institutes and is subsequently codified, published, and made accessible in academic or professional journals. *Know-what* refers to knowledge of techniques; usually it can be codified and transferred through the commercial marketplace. *Know-how* refers to the combination of skills, analytical capacity, and intellectual, educational, and physical dexterity of individuals and systems to effectively combine the know-why and know-what to innovate. This capacity is often learned through education and technical training and perfected by doing. This makes it more difficult to codify and also more difficult to transfer to others. Finally, know-who, which "*involves information about who knows what and who knows how to do what,*"[8] is becoming increasingly important in biotechnology-based industry. The breadth of knowledge that is required to innovate has expanded to such extent that collaboration has become indispensable. In today's context, know-who also requires knowledge of—and access to—private-sector knowledge generators who, at times, may hold back the flow of crucial enabling information, expertise, and knowledge. Know-who knowledge is seldom codified; instead, it often accumulates within an organization or, at times, in communities where a cluster of public and private entities are all engaged in the same type of research and development. These clusters often exchange technologies, biological materials and resources, and pursue common staff training or cross-training opportunities.

Third, each of the above-mentioned types of knowledge is likely to be subject to some form of exchange costs. Different types of knowledge are likely to be delivered by different actors.[9] Depending on the nature of the knowledge (whether it is easily codified as well as the cost of exchanging it), the exchange may be an arms-length market transaction (for example, contracts or spot markets) or may involve nonmarket organization (for example, intracompany transfer, development and use in the public sector or via collective institutions).

The public sector is optimally structured to create know-why scientific knowledge for the public good. Private companies and markets are generally well suited to managing codified knowledge, often in the form of patents. Collective organizations are often best for delivering knowledge, such as know-how and know-who.[10] Different domains, moreover, favor different formal or informal IP mechanisms, according to organizational objectives and abilities. Academics developing pure science emphasize publication and the use of copyright, while actors developing technology look to patents and trade secrets to protect interests. Collective institutions use less formal, open, pooled or networked knowledge, controlling access through a shared language, a common culture, and extensive collective experience.[11]

In sum, to understand networks and networked knowledge, we must consider the nature of the knowledge being developed and used, the transactional forms mediating the exchanges, and the institutional structure of the relationships that manage the development and use of IP. Increasingly, networks or communities of innovators are locating in aggregated clusters.

5. CLUSTER THEORY

"Location, location, location," the battle cry for property realtors everywhere, is increasingly becoming the key phrase in studies of innovation dynamics and knowledge-based growth. Theories about how innovation occurs, and more specifically about how and why companies and other actors co-locate in clusters, are incomplete but continue to evolve. As our understanding of innovation grows, so does our ability to direct its revolutionary power.

Widely used both in the academic literature and among economic development practitioners, the term *cluster* is helpful. The Oxford English Dictionary defines the generic term to mean a "*group of similar things, especially such as grow together*." Although companies and various not-for-profit entities in the same sector or product market have been observed since the beginning of recorded economic history to locate themselves in specific geographic regions (rather than spreading out evenly across the geography or economy), the search for ways to encourage clustering has only recently begun. Economists first began to develop models to explain such agglomerations in the 1700s. By the mid-1800s, economists were beginning to develop new theories and undertake intensive analyses of the phenomena. While that work continued on and off into the 1900s, the rise to dominance of the neoclassical economic paradigm after 1950 pushed these studies (and related policy prescriptions) to the margins.

That all changed in the 1990s. Beginning in the early part of the decade, economists began to refocus their attention on the microeconomic foundations of growth. After a decade of stagflation, new "conservative" governments shifted to a low-inflation macroeconomic stance and began to look for new microeconomic options to accelerate productivity and economic growth. Michael Porter's well-timed release in 1990 of the *Comparative Advantage of Nations*[12] reintroduced the concept of clusters, this time in a paradigm that posited that local competition is the primary dynamic behind cluster development and sustainability. This concept dovetailed with the shift in strategies by governments. Since then, the general concept of "*similar things… growing together*" has been applied widely to economic and industrial policy around the world.

Cluster theory is now a fabric of many threads drawn from economic geography, regional economic innovation systems, national innovation systems, and knowledge transfer and social networks. While there is no consensus on a complete theoretical explanation for clusters, a few threads are becoming common to most explanations of the phenomena. These return to the basic observations by Marshall,[13] who identified three clear and straightforward sources of external economies (Krugman[14] calls them "*centripetal forces*") that explained the location of some industry: knowledge spillovers, related and supporting industry, and specialized labor markets.

Much of the literature on clusters focuses on the potential for external economies to develop from information spillovers. Beyond the basic economies of scale in knowledge-based industry, external factors can significantly influence the industry due to "*mysteries being in the air*."[15] The literature on "*national systems of innovation*" (initiated by Lundvall[16]) posits that such systems involve "*that set of distinct institutions which jointly and individually contribute to the development and diffusion of new technology and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artefacts which define new technologies.*"[17] In other words, innovation now involves and generates significant externalities—innovators increasingly rely on an array of formal and informal collaborators, and the efficacy of those relationships will determine their ability to successfully launch a new innovation. Mowery and Oxley[18] point out that these systems must include more than the research actors. They also require public programs intended to support technology adoption and diffusion, as well as an array of laws and regulations that define IP rights and manage discovery, production, and marketing.

Studies have focused mostly on the role of universities in innovation systems. The traditional role of a university is to generate and diffuse basic or explorative knowledge and to develop a skilled academic and technical labor force. However, these traditional roles (in terms of knowledge-generation activity and culture) are evolving. As Cooke[19] argues, a strong local science base needs to be complemented by a thick entrepreneurial culture in both the regional business and academic communities. Brown and Duguid[20] suggest calling these connections "*communities of practice*." Not surprisingly, measuring such connections is complex and difficult because such knowledge is often tacit and nebulous.

A similarly large amount of research has concentrated on evaluating extensive local and regional networks of related and supporting industry (often called "backward linkages") and their access to large, sophisticated markets ("forward linkages"). Porter[21] analyzed 2,500 potential clusters around the world based on the strength and value of their arrays of forward and backward linkages. The Innovation Systems Research Network, a consortium of scholars examining 27 clusters in Canada, similarly evaluated the importance of industrial and supply-chain relationships on competitiveness and innovation. While these studies have shown that linkages are important, the evidence is still out on whether the linkages are a causal factor or are a result of effective innovation.

Finally, a number of researchers have attempted to evaluate the role of labor market dynamics for growth. These studies argue that when local labor markets expand and specialize, this creates incentives both for companies to co-locate and for specially skilled employees to migrate to those locations. This reduces the searching and negotiating costs for operating in the region. In addition, these labor force dynamics sustain and support the flow of knowledge among actors. Zucker, Darby, and Brewer,[22] for example, looked at the role of research stars such as high-impact academic researchers that were concentrated geographically, concluding that agglomerations of stars are positively correlated with greater local innovation. Stars appear to provide valuable signaling functions for capital markets to facilitate commercialization of new technologies and products.

Metcalfe[23] notes that Malerba's 1991 study of Italy identified two discrete, independent systems of innovation. One, typified by the computer software industry, is based on flexible networks of small- and medium-size companies, often co-located in distinct industrial districts (such as Silicon Valley). These companies were both very volatile and growing rapidly. The other type of system, which perhaps better reflects current biotechnology systems, is based on universities, public research laboratories, and large firms performing and commercializing R&D—called "*the triple helix*" by Etzkowitz and Leydesdorff.[24] It has been further argued that, regardless of the prevailing model, no institution can be self-contained in its technological activities.[25] All companies, large or small, have to rely on knowledge from other sources. Systems that support a company's ability to access, absorb, and use external knowledge can be critical to the growth of companies, sectors, and regions. This is especially so in the early stages of a technology's development or when a technology has a rapidly changing knowledge base, as is the case with biotechnology.

Critics argue that the term *cluster* is vague and has become mere rhetoric. Markusen[26] argues that the cluster literature involves "*fuzzy concepts*" based on "*scanty evidence*" that produces "*wimpy policy*." According to the OECD, the definition of a cluster "*provides little guidance for narrowing the scope of inquiry in a meaningful way*."[27] Similarly, according to Martin and Sunley,[28] "[Clusters have been] *accepted largely on faith as a valid and meaningful way of thinking about the national economy, as a template or procedure with which to decompose the economy into distinct industrial-geographic groups for the purposes of understanding and promoting competitiveness and innovation*." Finally, some critics argue that clusters can be interpreted to imply rising self-sufficiency, which may work against the economic benefits of specialization and open trade based on comparative advantage.

6. CLUSTER PRACTICE

No matter how vague the term, this has not prevented its rapid adoption. Economic development agencies in developed and developing countries have applied Porter's generalized approach to clusters, customizing it to their particular geopolitical region. More than 1,100 clusters have been examined in recent years,[29] but few of these have examined the research components of health or agriculture, and only three major studies have focused on clusters in the life-science area.

Ryan and Phillips,[30] for example, identified and categorized 14 life-science clusters in seven countries in 2001, concluding that life-science-based innovation clusters vary in scope and scale across the regions of Australia, Europe, and North America (see Table 1). Some clusters are discrete communities in which development and preservation are driven by clearly defined public policy. The communities often have names signifying their status as an innovation cluster (for example, BioBelt, BioValley, and Innovation Place). Ryan and Phillips discovered that most clusters were based on a core of biomedical research. In those that claimed to have an agri-food focus, the effort was often only a small, relatively insignificant adjunct to the core. There are very few established clusters dedicated to agricultural or agricultural biotechnology other than Canada's Innovation Place in Saskatoon, Saskatchewan; the Agri-Food Quality Cluster in Guelph, Ontario; and perhaps Adelaide Centre in Australia. In each case, a large percentage of the primary and supporting (private and public) actors are directly involved in food quality and agricultural biotechnology.

Table 1: Selected Life Science Clusters

Country	Region	Number of actors	Private sector presence	Ag/ag-biotech component
Canada	Innovation Place, Saskatoon, Saskatchewan	115	73%	29%
	Agri-Food Quality Cluster (AFQC), Guelph, Ontario	41	76%	49%
United States	Connecticut Bioscience Cluster	110+	98%	1%
	The Research Triangle Park (RTP), Raleigh-Durham and Chapel Hill, North Carolina	145	92%	3%
	BioBelt, St. Louis, Missouri and Illinois	1,183	90%+	24%
	Biotech Beach, San Diego, California	700	90%+	3%
Europe	Innovation Triangle, Edinburgh, Dundee and Glasgow, Scotland	428	95%	2%
	BioValley, France, Germany, and Switzerland	459	90%	6%
Australia	Qbio, Brisbane, Queensland	43	42%	5%
	BioHub, Sydney, New South Wales	28	75%	18%
	Bio21, Melbourne, Victoria	24	0%	4%
	Adelaide, South Australia	25+	65%	44%
	Perth, Western Australia	27	80–90%	20%

Source: Adapted from Ryan and Phillips.[31]

Cluster models appear to be very different.[32] The United States focuses on commercial outcomes and investment attraction, placing key multinational companies (some might call them national champions) at the center of their regional clusters. In Europe, the public sector (universities and large research institutes) is the main driver. Canada's key clusters tend to be community led, while Australia appears to use a blend of cluster approaches. Phillips and colleagues[33] examined the seven Canadian biotechnology-based clusters studied through the Innovation Systems Research Network.[34] These seven communities represent a wide range of size, scope, foci and histories (table 2).[35]

Consisting of both large pharmaceutical and small biotechnology companies, the Montreal cluster is the largest biotechnology cluster in Canada. It benefits significantly from provincial-government programs and national research labs. Recent surveys identified 351 actors: 130 in human health, 26 in human nutrition, 12 in agricultural biotechnology; and seven environmental companies; 171 service and supporting enterprises; one government lab; and four related universities. As of 2002, 29 companies in Montreal had patented 234 locally invented technologies, but 89% of the patents were owned by the eight largest companies. Growth in the region since 1999—when only 14 companies had 66 patents in total—has been explosive.

The Toronto cluster is a two-part cluster: one part is dedicated to core biotechnology activities and the other to biomedical devices. Anchored by the Medical and Related Sciences (MaRS) Discovery District, the University of Toronto (U of T), and the Health Network have also been identified as primary knowledge generators. A concentration of companies is situated downtown while some skilled workers are concentrated in peripheral regions. It appears that once firms or organizations move from exploration to exploitation activities, they move to the neighboring cities of Etobicoke or Mississauga to take advantage of lower costs. This contributes to weak network coherence, although Mississauga appears to be more cohesive. While the U of T has a significant number of stars, it has historically been considered unsuccessful in facilitating spinouts. This has been variously cited as the reason for limited local expertise in biotechnology financing.

It is not yet clear whether London, Ontario has a distinct biotechnology cluster or whether the activity there is merely an extension of the Toronto cluster. With an established biomedical-devices competency that started in the 1970s, London would appear to be an early-stage, emerging biotechnology cluster focused on biopharmaceutical applications. Linkages among local actors appear to be weak, with most acknowledging that they are more connected to actors in the Toronto core than they are to one another.

The Vancouver cluster, which focuses largely on biomedical biotechnology, is essentially a research community with the University of British Columbia (UBC) at the core. UBC and, to a much lesser extent, Simon Fraser University, are home to almost 80 research stars who produce a wide array of IP. While there have been some spinouts from UBC, more than two-thirds of which have survived at least five years, the prime focus of the cluster is on developing IP rather than products. Government and industrial support has not fundamentally altered the cluster. Early research suggests that lifestyle may be one of the critical factors that sustains the university and attracts both companies and individuals to the region.

The Saskatoon cluster is almost purely an agricultural-biotechnology cluster, focused predominantly on oilseed crops. While the university is home to the largest number of researchers in the community, many of the stars and much of the IP that is developed and used have come from federal labs. NRC's Plant Biotechnology Institute (NRC/PBI), the focus of considerable research collaboration, appears to share leadership with the local industry association, AgWest Bio. While the cluster is research focused, it has succeeded in commercialising world-first genetically modified plants, vaccines, and inoculants. Recent public investment in the university—including the Canadian Light Source Inc. (CLSI) synchrotron project and various genomics projects—has the potential to change the direction of the cluster over the coming years.

Table 2: Comparison of Canadian Biotechnology-Based Clusters

Cluster	Focus	Core actor(s)	Stars	Preliminary observations
Montreal	Pharmaceutical and biotechnology	A handful of generic and multinational-enterprise patent drug companies	70	• provincial government leads in terms of progressive policies • 15 spinouts University of Montreal
Toronto	Biotechnology and biomedical	Medical and Related Sciences (MaRS) Centre; University of Toronto; and the Health Network	47	• concentrated in Toronto at exploration stage; moved to peripheral regions (Etobicoke) at exploitation stage • limited network coherence
London	Biotechnology / biomedical devices (established in 1970s)	University of Western Ontario; Robart's Research Institute; and Lawson Health Research Institute	5	• early-stage biotechnology cluster • cluster or merely TO 'cohort'? • transportation considered a weakness
Vancouver	Biotechnology	University of British Columbia	80	• producer of IP, not products
Saskatoon	Agricultural biotechnology	National Research Council-Plant Biotechnology Institute; AgWest Bio	45	• research based • new investments in genomics, Canadian Light Source Inc., and University of Saskatoon may change direction
Ottawa	Biomedical and biotechnology	Gamma Dynacare (Ottawa Life Sciences Technology Park)	6	• more than 40 research institutes • 18,000 people employed in life sciences • 15–20 spinouts
Halifax	Pharmaceuticals, health, nutraceuticals, information technology, and biomedical	none	min.	• a variety of companies, with little product focus • not clearly a cluster • weak networks

The evidence available to date suggests that, based on the traditional definition of the concept, neither Ottawa nor Halifax are clusters. While Ottawa appears to have a large number of research institutes, its identifiable biotechnology cluster is quite small. As of 2002, there were only 47 actors: 30 small biotech companies, six government labs, one connected university, and ten service/support organizations. Only two of the Ottawa-based companies had generated patents by 2002, and the University of Ottawa had only a few stars and limited success with patents (11 as of 2002). Meanwhile, Halifax hosts a variety of companies with little or no market focus. Actors are not focused on any specific technology or product application. Instead, some actors are in the heath sector (devices, pharmaceuticals, information technology, and neutraceuticals), while others work on horticulture, environmental applications, and food quality. There is currently no obvious anchor organization, and actors in the region are loosely connected. In contrast to most other clusters, this one has seen little investment in infrastructure in the past few decades. Local surveys suggest that there has been little or no success in facilitating technology transfer, which has led to limited engagement between business and academic scientists.

This review of Canada's clusters offers a number of insights into cluster practice. Although biotechnology-based industries have common, "deeper science" aspects, they appear to differ widely in terms of organization. The significant differences in size (Montreal versus Saskatoon), market focus (core biotech in Vancouver versus medical devices in Toronto), and cohesion (strong in Saskatoon and Montreal but weak in other centers) suggest that the way in which the cluster is organized—its position in a product or technology life cycle and how its actors interact—can vary widely.

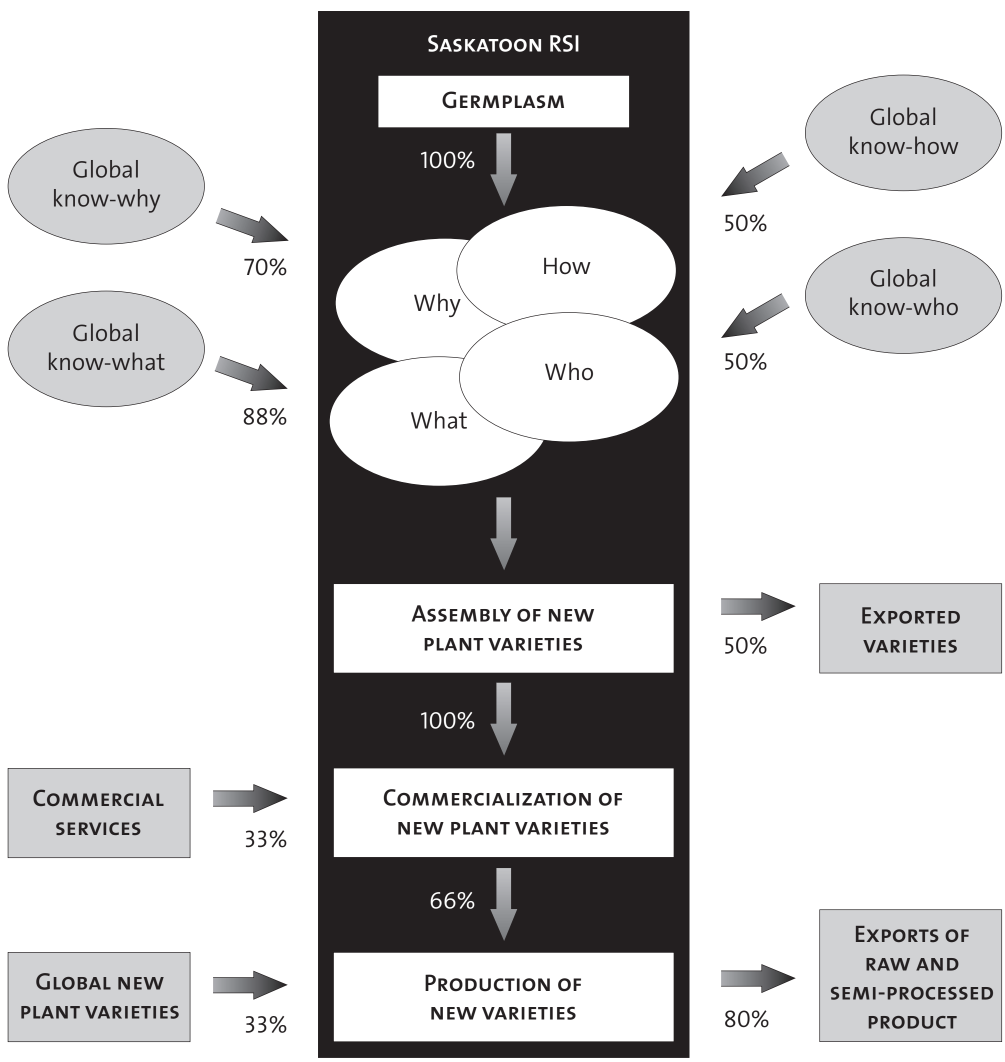
Phillips[36] examined the dynamics of the Saskatoon-based ag-biotechnology cluster by focusing on knowledge flows. Wolfe and Gertler[37] suggest that a more-sophisticated approach to clusters is to consider them as regional systems of innovation that embody local interdependencies (what Wolfe and Gertler call "*local buzz*") and engagement with the broader international economy ("*global reach*"). A local buzz and global reach, or entrepôt, approach would highlight the balance needed between local, regional, national, and global capacities. Phillips[38] analyzed the stocks, flows, and accomplishments of the Saskatoon innovation system through the mechanism of an entrepôt model. It looked at the community's capacity to create knowledge, use knowledge, and commercialize new products. Saskatoon's claim to fame is arguably the development of canola (based on its record as the lead innovator and early adopter of all new traits over the past 40 years). Analysis showed, however, that a significant share of the applied research to develop the processes used in the creation of those varieties has been done in other countries. Moreover, much of the application-based research (for example, uses for new oils) is happening elsewhere. This suggests that Saskatoon has actually operated in a niche of this global, knowledge-based industry—as an entrepôt undertaking and assembling the know-why, know-how, and know-who of varietal breeding and primary production—but that the bulk of the activities up- and downstream of that stage in the production system are now, and may continue to be, carried on elsewhere. Figure 1 illustrates the relationships between the global industry and the Saskatoon entrepôt.[39]

7. CLUSTERS AND IP MANAGEMENT

Research is increasingly generating networked knowledge. This new asset potentially has new economic and commercial value, but it faces a new set of complex relationships and transaction costs. Recent research into cluster structures in the Saskatoon-based agricultural-biotechnology cluster suggests that one driver for agglomeration may be the development of a cost-effective, efficacious system of IP management. This community has been host to a number of highly competitive multinational companies, has patented many critical life-science inventions, and has delivered a number of world-first technologies to the marketplace. Its experiences offer some insights into another possible objective of clusters.

In a perfect world with full information and no transaction costs, complete contracts to finance and undertake common research would be optimal. However, we know that transaction costs (especially with highly fragmented IP rights) are nontrivial, and that the probability of having a commercial success in any given project is relatively low (usually, less than 10% of projects return the costs of investment). Hence, as transaction costs rise, full contracts become less likely. Furthermore, it tends to be difficult to measure the often-tacit inputs to research programs. Attributing respective contributions to success in the discovery process is also tricky. In addition, any resulting outputs often have very specific uses, which makes them hostage to their potential users. These factors can lead to a classic case of "hold up," whereby investors may not be willing to invest because their bargaining power after any research breakthrough would be very

Figure 1: The Saskatoon Biotechnology Entrepôt and Its Global Connections



Source: Phillips 2002 [36]

low.[40] While long-term contracts would be one way to resolve this conundrum, few contracts will be negotiated for one-time projects. An alternate solution is to use social capital (for example, norms and relationships) in a community or cluster. In essence, by using the cluster as the basis for a research relationship, the difficulties of negotiating one-time deals can be overcome: the research community operates as if it is engaged in repeated exchanges. Participants in a cluster thus often will not negotiate each deal as if it were a one-time event. Rather, they would be willing to leave some terms and conditions unspecified, on the (usually justified) assumption that the strength of overall community relationships would reduce the probability that any company or actor would act with guile.

The Saskatoon-based agri-food research cluster gives a sense of how clusters or regional systems of innovation can lower transactional costs.[41] This community is credited with a series of world-market firsts (for example, agrobacterium technologies) and product firsts (for example, herbicide-tolerant canola and flax). It took the lead in the development of the concept for a National Agricultural Genome Centre (which, although unsuccessful in reaching that particular goal, ended up providing a model for Genome Canada) and leads four major genomics agri-food projects. Most of these initiatives were developed without formal *ex ante* contracts; instead, leaders in the community developed the projects under the assumption that any gains and losses would be apportioned equitably, or at least that any short-term losses would be compensated by future joint projects. This apparent altruism is nothing more than an extension of the community's business model, as Phillips and Khachatourians[42] and Phillips[43] show in their examinations of how Saskatoon became a national center for the generation, transmission, and consolidation of noncodified knowledge in the agricultural biotechnology industry. At the core of this community are Agriculture and Agri-food Canada and the National Research Council. Both have extensive arrangements with each other, public universities, and private companies, which allow them to learn from their collaborations, thereby adding further to the local stock of know-how knowledge and providing a visible, efficient point of entry for nonresidents to access know-how and know-who capacity. The public institutes also provide a home base for research stars, which, according to Zucker and colleagues,[44] reduces the search costs for other researchers and subsequent commercialization. The largest single geographic concentration of stars and near-stars in the canola research world is located in Saskatoon, where 11 out of 69, or 16%, of the top scientists live and work.[45] Phillips and Khachatourians[46] report that multinational enterprises (MNEs) and smaller companies in Saskatoon were primarily attracted by the presence of key personnel in collaborating and competing organizations. Although the public and private institutions have changed in recent years, the social capital built up appears to continue to sustain collaborative activities.

8. LESSONS FOR DEVELOPMENT AND IP MANAGEMENT

Knowledge-based development is inherently different from traditional industrial development. While a traditional industrial strategy that promoted infant industry via protection made some sense in the industrial world, it is not clear whether it has any value in a knowledge-based world.

This emerging global pipelines/local buzz cluster model of innovation poses some serious challenges for development policy. Much of the current biotechnology-development effort has a strong mercantilist orientation that focuses on self-sufficiency. Governments at all levels in many countries are actively using their tax and fiscal policy to encourage more local R&D and to attract global companies to relocate their R&D programs so that higher-value exports can be generated and imports replaced. This often involves preferential support for national champions or exclusive deals to encourage MNEs to relocate their activities. Usually governments do this without considering the corresponding relationships and interactions that knowledge-based companies require to succeed. If innovation can be thought of as limited to within a company or within a regional or national community, then such a narrow approach might have some chance of succeeding. But the increasing complexity and fragmentation of knowledge and IP rights in the biotechnology sector suggests there likely is no single center that can effectively develop new biotechnologies or applications. Networking and partnerships are going to be the order of the day. And, if innovation is truly global, as appears to be the case in many of the life sciences, then narrow, mechanistic, self-sufficiency strategies may either simply fail or prove counterproductive.

One key to success in these circumstances will be to invest in the institutions and mechanisms that encourage the development of and access to the four knowledge factors (know why, know what, know how and know who), which provide the foundation of a research economy. A number of strategic options might be appropriate. First, effective mechanisms to protect and legally transfer IP across international boundaries are the price of admission to collaborations. Second, clusters that are open to new knowledge, IP, and highly qualified personnel and companies will likely be more successful in creating and commercializing new biotechnologies or related products. Third, simply declaring that a region is a cluster is not enough. There must be some regional investment in infrastructure, as well as openness and/or support for the emergence of one or more anchor institutions. While private companies may have the greatest drive for commercial development, governments often have only limited direct influence on their location and operation. Governments can strengthen their hand by considering how their universities or public research labs can be used to anchor the community. Ultimately, the goal should be to create some platform to generate mysteries in the air. Whatever forms this platform takes, it will need to generate both local buzz and tap into global pipelines.

In short, innovation clusters are very attractive economic development and IP management tools, but they must be nurtured with an appreciation for their partial and incomplete nature. Part of a global innovation system, they cannot thrive if cut off from the lifeblood of that system—ideas, skilled labor, and collaborative platforms. ■

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