European Planning Studies Vol. 17, No. 2, February 2009

Life Sciences and Regional Innovation: One Path or Many?

MERIC S. GERTLER* & TARA VINODRAI**

*Program on Globalization and Regional Innovation Systems, Munk Centre for International Studies, University of Toronto, Toronto, ON, Canada, **Department of Geography and Environmental Management, Centre for Environment and Business, University of Waterloo, Waterloo, ON, Canada

(Received January 2007; accepted August 2008)

ABSTRACT *Despite the widespread interest of national, regional and local governments in promoting their own biotechnology industry, it is now well known that this sector exhibits characteristically high levels of geographical clustering in a relatively small number of locations. However, what is less well understood is how these regions have emerged and evolved through time. While there is a tendency to conceive of the necessary and sufficient conditions in fairly universal and formulaic terms—strong research universities with leading medical schools, a well-developed local venture capital industry, and a deep labour market in highly skilled scientific occupations are factors that are most commonly emphasized—we contend that the evolutionary pathways followed by individual regions with successful life science sectors are far from identical. Differences in local historical, geographical and institutional conditions are likely to shape and constrain the subsequent actual evolution of life science industries in particular places in distinctive ways. In this paper, we examine this issue through the lens of a national, 5 years, collaborative research initiative analyzing cluster development and evolution in Canada. We present findings from the study of life science industries in Canada's three largest city regions (Montreal, Toronto and Vancouver), as well as in three smaller city regions (Ottawa, Saskatoon and Halifax). Despite the conventional wisdom that public and private research institutions determine the trajectory of life sciences cluster development, our research suggests that a multiplicity of institutional and non-institutional actors, alongside background regional conditions and chance events, provide the impetus for cluster emergence and growth. We find that regional-scale policy interventions within an overarching national institutional framework have both intended and unintended consequences in helping determine the shape and nature of each region's life science clusters. Finally, we find that both local and non-local sources of knowledge are important to sustaining growth, innovation and dynamism within life science clusters.*

Correspondence Address: Meric S. Gertler, Program on Globalization and Regional Innovation Systems, Munk Centre for International Studies, University of Toronto, Toronto, Ontario, M5S 3K7, Canada. Email: meric.gertler@utoronto.ca

ISSN 0965-4313 Print/ISSN 1469-5944 Online/09/020235–27
DOI: 10.1080/09654310802553514

1. Introduction

Biotechnology and life science-based industries more generally, are now viewed as quintessential elements of the contemporary knowledge economy, and as important drivers of economic growth and dynamism in developed and developing countries alike (Feldman, 2000b; Rosiello, 2008; Thorsteinsdóttir *et al.*, 2004). In recent times, these industries have become the focus of economic development strategies in many national and subnational jurisdictions, with the emphasis on biotechnology in particular (see Christensen, 2003; Feldman, 2003; Feldman & Frances, 2003). However, this somewhat narrow focus tends to overlook a number of related activities within the broader sphere of life sciences that are themselves very significant sources of innovation and employment (Cooke, 2007, 2008). This approach suggests that it is more useful to consider the life sciences more broadly, to include a wider range of activities related to—but not limited to—biotechnology and that draw upon a variety of different technologies and knowledge bases.

Life science-related activity is anticipated to generate employment and income for regions and nations, contributing to their economic competitiveness and prosperity and generating highly skilled, well-paying jobs. Moreover, given potential convergence with information technologies, nanotechnologies and other areas of applied science, life science activities are expected to provide a strong foundation for future innovation and growth. For these reasons, academics and policymakers have paid increasing attention to understanding the enabling conditions, institutional forces and policy mechanisms that have nurtured and developed the innovative capacity and economic success of life science activities in particular regions and nations. Despite the widespread interest among national, regional and local governments in promoting their own biotechnology industries, it is now well documented that this sector exhibits characteristically high levels of geographical concentration or clustering in a relatively small number of locations (Cooke, 2005; Cortright & Mayer, 2002).

However, what is less well understood within the literature is how these regions have emerged and evolved through time. While there is a tendency to conceive of the necessary and sufficient conditions in fairly universal and formulaic terms—strong research universities with leading medical schools, a well-developed local venture capital industry, and a deep labour market in highly skilled scientific occupations are factors that are most commonly emphasized—we contend that the evolutionary pathways followed by individual regions with successful life science sectors are far from identical. In our view, the prevailing wisdom gives short shrift to the differences in local historical, geographical and institutional conditions that shape and constrain the subsequent actual evolution of life science industries in particular places.

In this paper, we examine this issue through the lens of a national, 5 years, collaborative research initiative conducted by the Innovation Systems Research Network (ISRN) analyzing cluster development and evolution in Canada (see Wolfe & Gertler, 2004). We present findings from the study of life science industries in Canada's three largest city regions (Montreal, Toronto and Vancouver), as well as in three smaller city regions (Ottawa, Saskatoon and Halifax). In taking a comparative perspective, we emphasize both the similarities and differences in the development of life sciences in these six urban centres, highlighting the importance of each region's distinctive economic and institutional context.

We proceed by asking a number of key questions related to the emergence and evolution of the life sciences innovation system in Canada. What key events and decisions fostered the emergence and subsequent trajectory of the life sciences activities in each of the six regions, and how did each local industrial concentration evolve through time? What kinds of knowledge assets and institutions have been most important in supporting this evolution, and to what extent must they be present locally? What role does public policy at various levels play in setting the initial conditions and fostering the local development of the industry? In particular, how important are national systemic influences relative to the role of regional innovation systems in shaping the developmental trajectory of life science industries in each of our case studies. Finally, how dependent are local firms on unique knowledge assets for their innovative success, and how important are local versus non-local knowledge sources?

In answering these questions, our broader objective is to contribute to our understanding of cluster emergence and the evolution of knowledge-intensive industries from both a theoretical and public policy viewpoint. Despite the conventional wisdom in the literature that asserts public and private research institutions often determine the trajectory of life sciences cluster development, our research suggests that a multiplicity of institutional and non-institutional actors, alongside background regional conditions and chance events, provide the impetus for cluster emergence and growth. Furthermore, we find that regional-scale policy interventions operating within an overarching national institutional framework have both intended and unintended consequences in helping determine the shape and nature of each region's life science clusters. Finally, we find that both local and non-local sources of knowledge are important to sustaining growth, innovation and dynamism within life science clusters. In this sense, the literature's predominant focus on local knowledge-producing organizations as the source of knowledge-based growth seems somewhat misplaced.

2. Cluster Development, Innovation and Path Dependency in the Life Sciences

Economic geographers, economists and other social scientists have had a longstanding interest in understanding how geographical concentrations of firms, institutions and other economic actors specialized in particular economic activities evolve through time. More recently, this interest has been paralleled with questions about the advantages that accrue to firms located within such "clusters" in terms of their increased ability to learn, innovate and tap into knowledge networks (Asheim *et al.*, 2006; Porter, 2000). Within this literature, scholars have relied heavily on case studies of knowledge-intensive activities such as biotechnology (Casper & Murray, 2005; Coenen *et al.*, 2004; Cooke, 2001, 2005; Feldman, 2003; Feldman *et al.*, 2005; Owen-Smith & Powell, 2004). In fact, biotechnology and life sciences are held up as paradigmatic examples of activities which tend to cluster in particular locations. For example, in the USA, San Francisco, Boston, San Diego and Washington have well-known clusters of innovative firms, research-intensive universities, government laboratories and venture capital firms participating in the biotechnology and life sciences arena (Cortright & Mayer, 2002; Feldman, 2003). Similarly, in the UK, Cambridge is often identified as a successful life sciences region (Cooke, 2005).

The literature on knowledge-intensive clusters in biotechnology and the broader life sciences highlights a number of conditions important to their economic performance. These include the presence of a local knowledge base arising from strong and vibrant research institutions, venture capital, a reservoir of local entrepreneurial experience, specialized services and infrastructure, as well as policy support (Prevezer, 2001; Cortright & Mayer, 2002). However, the precise background conditions and events that trigger the emergence and development of clusters are less well understood. A number of theories explaining why life sciences regions emerge in particular locations have been put forth. For example, Cooke (2005) argues that in science-based industries such as the life sciences, it is increasingly the location of research and development (R&D) related infrastructure such as research-intensive universities and laboratories that encourages the continued clustering of firms in these areas. Feldman and Francis' (2003) study of biosciences in Washington points to the subsequent downsizing and/or closure of pre-existing government laboratories as important triggers to cluster development in that region. While the literature recognizes the key role of public research institutions as anchors to knowledge-intensive activity, it tends to downplay the implicit and explicit roles played by other public policies at various scales of governance (see Cooke, 2005).

Evidence from the biotechnology and life science sectors has also been critical in stimulating a better understanding of learning dynamics and knowledge flows within clusters. After all, if knowledge is easily transmitted over long distances, then those sectors that are highly knowledge-intensive ought to be increasingly dispersed geographically. And yet, as noted above, biotech and other life science-based industries exhibit strongly concentrated geographical patterns of development. Addressing this paradox, Asheim and Gertler (2005) point to the literature on knowledge spillovers, which documents the highly localized geography of patents and patent citations in analytically oriented fields such as biotechnology (see Feldman, 2000a). Furthermore, they note that Zucker and Darby's (1998) work on "star scientists" emphasizes the highly uneven geographical distribution of leading scholars conducting biotechnology-related research, and also demonstrates the benefits of co-location between these star scientists and start-up firms. Such proximity fosters the establishment of collaborative relationships, which promotes joint local knowledge creation and sharing. Star scientists, alongside scientific entrepreneurs (Feldman *et al.*, 2005) and civic entrepreneurs (Wolfe & Gertler, 2004), become actively engaged in the innovation process itself and act in a leadership role by helping to build local networks. In doing so, these actors help to create local "buzz", actively engaging in the local creation and circulation of knowledge (Bathelt *et al.*, 2004).

However, recent research suggests that the local nature of these processes can indeed be overestimated, and that both local and non-local knowledge flows are important to the innovative dynamism and success of knowledge-intensive clusters. For example, Owen-Smith and Powell (2004) suggest that scientists participating in international networks act as conduits to bring new knowledge into the local cluster, complementing locally produced knowledge to accelerate successful innovation. Using co-authorship of published scientific papers as an indicator of collaboration, Coenen *et al.* (2004) demonstrate that non-local knowledge flows can in fact be quite strong. Local scientists participating in biotechnology-related research in Medicon Valley (part of the Öresund region spanning the border between Denmark and Sweden) actively collaborate with colleagues across Europe and the USA. Therefore, in addition to creating local buzz, these same individuals build "global pipelines", which together facilitate the local and non-local transfer of knowledge (Bathelt *et al.*, 2004). Yet, the relative importance of local and non-local flows of knowledge remains somewhat indeterminate and a point of contention within the literature on clusters, innovation and learning.

3. The Canadian Life Sciences Industry in Global Context

Given the active and growing interest in biotechnology and related fields, there have been numerous efforts to assess the size and scope of the Canadian life sciences industry. These studies have tended to focus narrowly on core, dedicated biotechnology firms (DBFs) and their innovative capabilities (Industry Canada, 2005; Statistics Canada, 2003, 2004, 2005a, 2005b; Traoré, 2006), taking the OECD (2002) definition as their guiding concept: "the application of science and technology to living organisms as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services". Human health represents the largest subsector within the Canadian biotechnology industry, measured in terms of numbers of firms. However, Canadian biotech firms also participate in a number of other areas of specialization including agriculture, forestry, food processing, aquaculture and environmental biotechnology (Statistics Canada, 2005a). Recent analysis of patenting and patent citations confirms this primary focus on human health alongside specializations in niche areas such as forestry, aquatic sciences, environment and animal sciences (Science-Metrix, 2005).

Between 1997 and 2003 Canada's biotechnology industry saw a substantial increase in the number of firms and employees (Table 1), consistent with trends observed in the global biotechnology industry (Ernst & Young, 2005a, 2005b). Firms in the Canadian biotechnology industry tend to be small, with more than 70% of firms having fewer than 50 employees. However, Canada's largest firms (150 employees or more), accounting for slightly less than 15% of all biotechnology firms, generate more than 60% of revenue in the industry. While large firms account for a disproportionately high proportion of the industry's revenue, the R&D expenditures of these large firms were collectively lower than small- or medium-sized Canadian firms (Statistics Canada, 2005a).

In 2004, Canada's biotechnology industry ranked first in biotechnology R&D expenditures per employee, second only to the USA in terms of number of firms and third globally in terms of revenues (BIOTECanada, 2004; Ernst & Young, 2005a). In terms of scientific publications and patent output, Canada ranked somewhat lower. Between 1992 and 2003 the US Patent and Trademark Office (USPTO) granted more than 2400 biotechnology patents to Canadian firms, placing Canada in fifth place behind the USA, Japan, Germany and UK. In terms of scientific publications in international, peer-reviewed journals in biotechnology and related fields, Canada ranked sixth globally (Science-Metrix, 2005).

Within Canada, biotechnology-related activity is concentrated in three provinces: Ontario, Quebec and British Columbia. In 2003, these three provinces accounted for

Table 1. Canada's biotechnology sector

	1997	1999	2001	2003
Number of firms	282	358	375	490
Number of employees	9019	7695	11,897	11,863
Revenues ($ millions)	813	1948	3569	3842
R&D expenditures ($ millions)	494	827	1337	1487
Number of products/processes in the market	1758	6597	9661	11,046
Financial capital raised by biotechnology firms ($millions)	467	2147	980	1694

Source: Statistics Canada (2003, 2004, 2005a).

more than 70% of all biotechnology firms in Canada and 80% of biotechnology revenues (Table 2). Quebec led in terms of total number of firms, employment, R&D expenditure, and financial capital raised. However, Ontario followed closely behind in terms of numbers of firms, employment and R&D expenditures and had significantly higher levels of revenue generation. British Columbia generally lagged behind these two provinces, although it surpassed Ontario in terms of financial capital raised and Quebec in terms of revenue generation.

Within these three provinces, biotechnology firms are highly concentrated within major metropolitan centres: Toronto, Montreal, Vancouver and—to a lesser extent—Ottawa (Graytek, 2005). However, smaller, specialized centres for biotechnology exist outside of these metropolitan regions—most notably in Saskatoon, which is home to a noteworthy agri-biotech industry specializing in canola (rapeseed) biotechnology, and Halifax, which has strengths in both human health and aquatic biotechnology. As noted above, this spatial concentration of the biotechnology industry is not unique to the Canadian context.

4. Life Science Activity in Six Canadian City Regions

The above discussion highlighting Canada's position in the global biotechnology industry is based on a narrow definition of what constitutes the biotechnology industry, focusing primarily on DBFs. While this standard definition facilitates international comparison and benchmarking, it imposes certain limitations on a more extensive analysis of life science-based industries. As noted earlier, our research programme was explicitly designed to document and understand sources of variation in the industrial dynamics of life sciences activity across both large, diverse urban economies and smaller, more specialized regions. Our research revealed that "life sciences" can take many different forms, going well beyond biotechnology strictly defined, to incorporate a range of related bioscience activities that draw upon a variety of different technologies, knowledge bases, and occupations and skill sets. The evidence for this analysis is drawn from a 5-year national study of cluster dynamics in Canada. Included among the larger research programme's 25 regional case studies were the six cases focusing on the emergence and evolution of life sciences activity whose findings are reviewed and synthesized in this paper: Toronto, Montreal, Vancouver, Halifax, Ottawa and Saskatoon.

Locally based researchers adopted a common methodology to study each of these cases. Our evidence base draws on the rich, empirical material derived from 354 in-depth, semi-structured interviews conducted in the six case study regions. Participants were identified through a series of methods including Internet and industrial database searches, mining background documents and inter-personal network referrals to construct a list of key informants. Private sector respondents were primarily managers in biotechnology and life sciences firms located in each area. However, to better understand the local context and to capture the broader set of local and non-local dynamics at play in each region, we also conducted interviews with representatives from government agencies, research institutions, venture capital firms, specialized support services (e.g. management consultants, law firms, contract research organizations (CROs)), and industry and civic associations involved in the life sciences. The precise mix of interview types varied from region to region, reflecting local differences in the composition and structure of life sciences activity in each case. For example, federally funded research laboratories in the life sciences are

Table 2. Key biotechnology indicators and ranking by region (2003)

	Number of firms (rank)	Employees with biotechnology-related activities (rank)	Biotechnology revenues, $millions (rank)	Biotechnology R&D expenditures, $millions (rank)	Financial capital raised by biotechnology firms, $millions (rank)
Canada	*490*	*11,863*	*3842*	*1487*	*1694*
Quebec	146(1)	3700(1)	480(3)	490(1)	563(1)
Ontario	129(2)	3508(2)	2026(1)	453(2)	253(3)
Manitoba	21(7)	1213(4)	145E(5)	56E(5)	X
Saskatchewan	34(5)	337(6)	94(6)	23(6)	X
Alberta	44(4)	727(5)	298(4)	88(4)	235(4)
British Columbia	91(3)	2173(3)	779(2)	370(3)	579(2)
Atlantic Region	25(6)	206(7)	21(7)	7(7)	3(5)

Note: E, use with caution; X, data suppressed due to confidentiality requirements.
Source: Statistics Canada (2005a).

present only in two of our cases—Montreal and Saskatoon. Table 3 provides a detailed breakdown of the types of interviews completed in each of the six case studies.

A variety of secondary sources were used to supplement and triangulate the information collected during the interviews. These included government documents, academic papers, consulting report, statistical databases (e.g. patent and bibliometric data), and articles from the popular and business press. The discussion presented in this paper relies on an analysis of both the primary and secondary sources used in this study, as well as research and analysis previously published by the collaborators involved in the national study (see Gertler & Levitte, 2005; Holbrook *et al.*, 2004; Lowe & Gertler, 2005, 2008; Niosi & Bas, 2003, 2004; Phillips *et al.*, 2004; Queenton & Niosi, 2003; Rosson & McLarney, 2004).

Table 4 provides an overview of the key characteristics of the six case study regions and highlights the variations in terms of the size, specializations, and levels of venture capital investments within each region. Toronto and Montreal emerge as the largest and most diversified life science centres in Canada and have a number of common features. Both Toronto and Montreal can be viewed as a "human health megacentres" with firms engaged in a diverse array of life sciences activity including biotechnology, pharmaceuticals, medical equipment and assistive technologies (MAT), and contract research (see Cooke, 2001, 2005). Both regions have a relatively young biotechnology sector situated within an older, more established life sciences sector. Furthermore, life sciences in Montreal and Toronto have each developed in the "classic" style of biotechnology clusters whereby "large-scale publicly funded research of high-quality created opportunities for entrepreneurship by academics and venture capitalists. Strong links with pharmaceutical firms strengthened the funding base of DBFs, some of which have been acquired by larger companies, while newer spinouts continue to emerge" (Cooke, 2003, p. 762). Both cities are home to many DBFs, a number of which are publicly traded companies. However, Toronto has a more diverse range of life sciences activity which includes DBFs, brand name and generic pharmaceutical firms, MAT companies, CROs, and specialized suppliers and professional services (Lowe & Gertler, 2005). In fact, Toronto has strengths in a number of specializations within the life sciences, including a strong pharmaceutical and medicine manufacturing base, as well as medical instruments, equipment and supplies manufacturing. On the other hand, Montreal has more pharmaceutical

Table 3. Interviews by region and type

	Halifax	Montreal	Ottawa[a]	Toronto	Saskatoon	Vancouver	Total
Life sciences firms	20	72[b]	12	90[b]	23	23	240
Contract research and mfg firms	0	7	0	2	0	7	16
Law and consultancy firms	3	0	0	0	0	5	8
Venture capital	2	0	1	4	5	5	17
Research institutions	2	0	6	3	15	2	28
Civic associations	3	0	1	8	7	1	20
Government agencies	3	0	5	2	8	7	25
Total	33	79	25	109	58	50	354

[a]Data currently not available.

[b]Includes medical and assistive technology (MAT) firms and pharmaceutical firms.

Table 4. Characteristics of case study regions

	Halifax	Montreal	Ottawa[a]	Toronto	Saskatoon	Vancouver
Core biotechnology[a]						
– Firms	10	80	10	55	14	48
– Employment	558	3238	736	2661	369	1701
Life Sciences						
– Firms[b]	$\sim$60	$>$270	100–140	$\sim$400	$\sim$40	80–140
– Employment[c]	1720	24,925	4635	35,585	1015	8835
Venture capital investments, 2000–2004 ($millions)[a]	1.7	844.5	96.0	237.7	6.4	604.5
Specialization	Human health; marine	Human health	Non-therapeutics; ICT-biotech convergence	Human health	Agriculture	Human health
Characteristics	Emerging; very small number of firms	Drug discovery; pharmaceuticals	Emerging	Scale; diversity	Ag-biotech; canola	Rapidly growing

[a]Industry Canada (2005).
[b]PriceWaterhouseCoopers (2003); BioNova (2004); OLSC (2004); Phillips *et al.* (2004); Graytek (2005).
[c]Spencer and Vinodrai (2005).

firms involved in drug discovery, and fewer generic drug producers, compared with Toronto. Niosi and Bas (2005) indicate that Montreal has a strong base of CRO activity with linkages to local pharmaceutical firms. However, other sources estimated that only 25% of clinical trials in Canada take place in Montreal (Montreal International, 2002).

While Vancouver is considerably smaller than Toronto or Montreal in terms of its firms and employment base, over half of its biotechnology firms are focused on human health (i.e. genomics, therapeutics, biopharmaceuticals and diagnostics), with the remaining firms focusing on applications in agriculture, forestry, aquaculture and environmental solutions (VEDC *et al.*, 2002). Unlike Toronto and Montreal, Vancouver has comparatively little activity in pharmaceuticals or medical equipment manufacturing; its main activities are research based and therefore, the primary outputs are primarily based on intellectual property (IP). In other words, Vancouver "does not manufacture commercial products—its product, if it has one, is intellectual property itself" (Holbrook *et al.*, 2004, p. 109). It should also be noted that Vancouver attracts a disproportionately high level of venture capital relative to its size.

The remaining three centres in the study are considerably more specialized in fields that closely reflect the broader characteristics of the region. For example, Saskatoon is situated within a region in which grain-based agriculture is a leading activity, and the region is considered to be one of the leading places in North America for R&D in plant-based biotechnology. While there are a number of multinational corporations in Saskatoon, the majority of biotechnology firms in Saskatoon are small (fewer than 50 employees) and young; over half of these firms were established after 1990 (Phillips *et al.*, 2004). Similarly, Ottawa's life science industry reflects the strengths of the local economy in the areas of information and communications technologies (ICT). In addition to research strengths in areas such as the cardiovascular cancer, and stem cells arising from the local education and research institutions, there is growth in fields related to non-therapeutics, including medical and assistive technologies and bio-products (e.g. bio-fuels) which are evolving as areas of convergence between biotechnology and ICT activities (OEOBC/OLSC, 2004). Ottawa's life sciences industry is relatively new and emerging; 30% of Ottawa's DBFs were established in the last 5 years (OEOBC/OLSC, 2004). Finally, Halifax has specializations in marine-related biotechnology. The region has a strong research base which is especially focused in the areas of nutraceuticals and functional foods, medical devices, tele-healthcare and marine biotechnology (BioNova, 2004). Despite the small number firms and low levels of employment and venture capital investment, Halifax is a key site of life sciences activity within the Atlantic region (BioNova, 2004; Industry Canada, 2005).

5. The Emergence, Formation and Development of Life Sciences Regions in Canada

The above discussion has established that the structure and characteristics of each of the six case study regions is quite distinctive, though it says little about how these regions have evolved to develop in this way. In this section, we explain this economic-geographical process by taking an historical perspective that draws attention to two aspects of cluster formation, growth and development: (1) the importance of distinctive regional context and historical background conditions that influence and shape cluster formation and growth and (2) the diverse group of institutional and non-institutional actors that catalyze change. In each of the cases, a different series of events and combination of local and non-local actors were responsible for triggering the emergence of life sciences activity in the region. By taking a path-dependent view of cluster formation, we hope to uncover the complex and diverse causal chains that shape the emergence and evolution of life science activity in each of these regions. In doing so, our analysis offers important insights into the role of public policy at various levels, pre-existing regional capabilities, historical continuities and discontinuities, and the role of public research institutions and other actors in explaining the different routes to cluster development.

5.1. *The Role of National and Provincial Systems of Life Sciences Innovation*

At the most fundamental level, federal and provincial policies have defined the context for life sciences development in different regions of Canada by shaping systems of healthcare, post-secondary education, public research organizations, the tax climate for R&D, and the regulatory framework for IP protection. Within the Canadian constitutional structure, each of these areas of government intervention is jointly shared between these two levels of government, meaning that, while certain commonalities exist across all provinces—publicly funded healthcare and post-secondary education being two of the most prominent examples—each provincial jurisdiction has the capacity to effect its own policies within this overarching federal legislative framework. Particular aspects of this inter-provincial variation will become clear in the following analysis.

Beyond these broad, systemic influences, a number of more focused federal government initiatives have been important in setting the stage for the development of Canada's life sciences industry. These include the introduction of the 1983 National Biotechnology Strategy, the provision of tax incentives to stimulate R&D expenditures (most notably through the Scientific Research and Economic Development—or "SR&ED"—tax credits), and the creation of federal laboratories focused on biotechnology-related research under the auspices of the National Research Council (NRC). The National Biotechnology Strategy was particularly instrumental in fostering life science activity, since it encouraged the introduction of policies by the provincial governments, in partnership with the federal government, which were tailored towards the specificities and preferences of each province. These provincial policies varied from generous funding councils and tax credits in Quebec, to fiscal incentives and targeted research funds in Ontario, to the creation of infrastructural support through "centres of excellence" in British Columbia (see Niosi & Bas, 2004, 2005).

While the federal and provincial governments aimed to implement "horizontal" and non-geographically biased policies, Niosi and Bas (2005, p. 58) argue that the outcome has been the concentration of life sciences in regions where "the best talents in human health research were already at work, and also those where venture capital agglomerated, as well as research universities and hospitals". In other words, the interaction of policies under the rubric of the National Biotechnology Strategy with other longstanding federal and provincial programmes to fund post-secondary education and research produced outcomes that were geographically very uneven. In this sense, while public intervention was critical in establishing the three largest clusters (Toronto, Montreal and Vancouver), this was not an explicit objective. However, our case study findings indicate that other policy instruments have been important in influencing the developmental trajectories of each region.

Especially germane here are the differences between the provincial drug programmes within the public medicare systems in Ontario, Quebec and British Columbia. These programmes comprise a critical component of public healthcare provision in each province, and have profoundly shaped the regulatory context for cluster development in Montreal, Toronto and Vancouver, respectively. In an effort to encourage multinational pharmaceutical firms to establish research and manufacturing facilities in the province, Quebec's provincial drug formulary provided a 15-year exclusive approval guarantee for brand-name drugs, even if generic alternatives were available. Conversely, since the 1970s, Ontario has required that medicare patients purchase cheaper generic versions of drugs whenever these are available (Lowe & Gertler, 2005). Consequently, while these two city regions account for a large proportion of pharmaceutical drug manufacturing in the country, generic drug producers constitute a larger and more visible presence within Toronto's life sciences cluster compared with to Montreal, where brand-name producers are considerably more prominent (Lowe & Gertler, 2005). Some of the Toronto-based generics, such as Apotex and Novopharm, eventually grew to considerable local and national prominence. In British Columbia, a drug provision strategy known as the Reference Drug Program, with a focus on cost containment, was implemented in 1995 under the New Democratic Party (NDP) administration. Although there are different views as to the actual impact in cost-savings promoted through this programme, what is clear is that this strategy is increasingly identified as the reason for the lack of a strong pharmaceutical presence in the province (Duffy, 2000; Legge, 2003; Mihlar, 2003). This example demonstrates how differences in policy approaches to healthcare provision at the provincial level have helped shape the type of biotechnology and life science sectors that have evolved in each city region.

5.2. *Regional Context, Historical Continuities and Exogenous Shocks*

In addition to provincial and federal policy decisions, a number of other historical background conditions and events at the regional level set the context for the different developmental paths in each of the six case study locations. First, recognizing existing regional capabilities and resources influencing cluster development highlights the importance of path dependency within each region. For example, in the Toronto case, a lengthy historical association with leading-edge biomedical research, coupled with the wide range of pre-existing economic activities that support modern biotechnology and life sciences (Lowe & Gertler, 2005, 2008) help explain the subsequent emergence of a deep and diverse life sciences cluster. The founding of Dow Pharmaceuticals in the 1880s by Shuttleworth and the establishment of the Connaught Laboratories at the University of Toronto in 1914 were early events signalling the development of Toronto's capabilities in pharmaceuticals and biomedical technology. Toronto has also been the site of a series of major medical breakthroughs, including the discovery of insulin by Banting and Best, the development of Pablum, the purification of heparin for human use, the first indigenously produced anti-rabies vaccines, and contributions to advances in modern medical technologies such as the cardiac pacemaker and the artificial kidney (Buist, 2004).

As for the influence of the structure of the regional economy, Lowe and Gertler (2005, p. 26) argue that Toronto "has developed a wide range of sophisticated service industries, including finance and professional/producer services, while retaining a strong manufacturing base in industries such as automotive, food products, electronics, specialized machinery and aerospace", which provide opportunities for cross-sectoral knowledge flows and convergence between technologies leading to innovation in a range of biomedical technologies and devices. Similarly, the established agricultural economy of Saskatchewan is reflected in Saskatoon's current specialization in agricultural biotechnology and Halifax's niches in marine-related biotechnology emerge from pre-existing strengths in other marine-related activities.

While our research reveals that pre-existing regional capabilities and industrial structure are important in shaping the developmental trajectory of life sciences activity, in some cases, historical discontinuities and exogenous shocks are as important in shaping the trajectory of the life sciences within particular regions. Again, the Ottawa case demonstrates this point vividly. Life sciences activity in Ottawa had been championed by local leaders beginning in the late-1980s. In fact, despite being the nation's capital and thus, home to a significant number of public research institutions, government funding agencies and regulatory bodies relevant to life sciences, the region did not experience momentum in the life sciences sector until the late-1990s. At that time, the dot.com bust acted as an exogenous force resulting in Ottawa's life sciences activities attracting political and financial support as investors turned away from Ottawa's ICT sector. In other words, the shock of the high-technology bubble bursting in the late-1990s unexpectedly raised the profile of the embryonic life sciences activities in the city. For this reason, it is not surprising that Ottawa's emerging strengths in life sciences rest at points of convergence between ICT and biotechnology, since many of the local entrepreneurs who entered into the biotechnology and life sciences field had previous experience in the ICT sector. The decline of the local ICT sector and new opportunities in the life sciences facilitated the cross-sectoral mobility of entrepreneurs with existing ties to the high-tech community.[1]

5.3. *Catalysts for the Local Development of Life Science Activity*

Most research on knowledge-intensive and science-based clusters such as biotechnology and life sciences highlights the crucial role of public research institutions in anchoring activity to particular locales and acting as leaders in developing local research activity (Cooke, 2005). However, other researchers argue that these institutions and actors lag rather than lead in the process of cluster formation and development (Feldman *et al.*, 2005). Evidence from our own research reveals that although public sector research institutions are almost always present, their role has varied from being critical and leading institutions to acting in a supporting way in responding to labour market requirements of local firms once the cluster has passed the "take-off" phase in its development (Wolfe & Gertler, 2004). In other words, while they may be a necessary component of any knowledge-intensive cluster, they are not always sufficient on their own to catalyze the cluster's development. When it comes to life sciences clusters, other local and non-local actors have often been critical in triggering the emergence and development of knowledge-based growth. Therefore, in the following discussion, we consider the role of public research institutions such as universities and government laboratories, as well as other actors such as lead or anchor firms, and industrial associations and civic entrepreneurs.

5.3.1. *The role of public research institutions*

Conventional wisdom accepts the importance of a local science base in biotechnology and life science clusters (Christensen, 2003). Our research reveals that public research institutions played a particularly important role in the emergence of a number of the case study clusters—notably in Saskatoon and Montreal, where federal government decisions to locate NRC laboratories in these cities had a propulsive effect on the development of the local sector (Table 5). In 1987, Montreal became the site for the NRC's $60 million Biotechnology Research Institute (BRI). The BRI has been an important catalyst to Montreal's biotechnology industry, with a significant portion of its budget allocated to financing collaborative research projects with private sector actors (Biotechnology Research Institute, 2004; Kuyek, 2002; Montreal International, 2004). In Saskatoon, the public sector's involvement in agricultural innovation dates back to the 1940s, with efforts centred on the development of canola (Kuyek, 2002; Langford *et al.*, 2002). The growth of agricultural biotechnology in Saskatoon built on these existing capacities in the region and was led by a number of public agencies (McKarney, 2001). The growing demand of various local groups, including farmers, for the public sector to invest in infrastructure and expertise in agricultural research resulted in a number of important public sector initiatives in the 1980s. The provincial government launched Innovation Place, a research park designed to foster the commercialization of research in the region. At the federal level, the NRC established the Plant Biotechnology Institute (NRC-PBI), and the federal government's agricultural ministry—Agriculture and Agri-food Canada (AAFC)—set up a major research centre in Saskatoon. These decisions were instrumental in attracting major inward investment in local research facilities by global agrifood players such as Monsanto, which were attracted by the critical mass of scientific expertise now assembled in Saskatoon. Not surprisingly, Phillips *et al.* (2004, pp. 4, 33) conclude that, "the real catalyst for formation [of the cluster] was the federal government's decisions to consolidate and refocus the national agricultural research units in Saskatoon in the 1980s ... This consolidation provided the base for attracting further private research".

5.3.2. *The role of lead/anchor firms*

Notwithstanding the prominent role of public research organizations in the emergence of the cases discussed above, this effect was far from consistent across all regions. Indeed, the evidence from other cases tells a somewhat different story emphasizing the importance of lead or anchor firms in each of these cases. For example, although there appear to be other important enabling events in Halifax, including the establishment of Nova Universities Technology Inc. (NU-TECH) in 1995, it was the establishment of Ocean Nutrition Canada that "lent credence to the Halifax life sciences sector" (Brar & McLarney, 2001, p. 6). The entrance of this lead firm was quickly followed by the creation of a technology transfer office: Dalhousie Medical School formed the Business Development Office (BDO) in 1999 to commercialize its research. By 2000, BDO had generated four biotechnology spin-off firms.

In Ottawa, MDS Nordion is considered an anchor firm for the city's emerging life science cluster (Graytek, 2005). The firm had its beginnings as an Ottawa-based crown corporation founded in the 1940s: Nordion International Inc. In 1991, the firm was sold to Toronto-based MDS Health Group and became MDS Nordion. The firm is estimated to have over 700 employees in the Ottawa region and conducts research and manufacturing activities in the field of radiotherapies (OLSC/OCRI, 2002).

Similar stories emerge when examining the more established biotechnology and life science centres included in our study. In most of the cases a single lead firm was identified by respondents as being critical to sparking the successful evolution of the local life sciences cluster. These firms have played a number of different roles, acting as a magnet to attract highly skilled workers to the region, producing spin-off firms, and

Table 5. Key triggers, events, strengths and challenges to the development of life sciences in the case study regions

	Halifax	Montreal	Ottawa[a]	Toronto	Saskatoon	Vancouver
Key triggering/ enabling factors	*Anchor firm*: BWG ONC *University*: Dalhousie-BDO	Pharmaceutical base NRC-BRI BioChem Public venture capital	OLSTP MDS Nordion Technology bubble burst	Diverse economy & research Financial market Allelix	Canola Innovation place NRC-PBI	*Anchor firm*: QLT *University labs*: UBC–UILO Local venture capital
Regional strengths	Local R&D base Major site for biotech activities in Atlantic provinces Emergent public and private support	Local R&D base Strong government support Pharmaceuticals Venture capital	Local R&D base Federal regulatory/ funding agencies ICT Civic support	Local R&D base Robust and diverse Largest financial centre	Public and private R&D collaborations Infrastructure for firm entry Large, active and sophisticated farmer groups	Local R&D base High rate of firm entrance Risk friendly, local venture capital
Regional Challenges	Financing Firms small, inward looking, R&D focused	Government dependence Risky drug discovery activities	No local life sciences VC fund Weak domestic linkages	*Profile problem*: local and international Weak commercialization systems	Public financing programmes too diverse and targeted? Undergoing change	*Research-based*: "IP vendors" Weak industrial infrastructure Sustainable?

encouraging entrepreneurial activity in the local community by other start-ups aiming to emulate their highly visible success. In Montreal, Vancouver and Toronto, a key role was played by pioneering firms in sparking latent entrepreneurialism within the region or providing a certain level of credibility and "inspiration" for other institutional actors in the region (Lowe & Gertler, 2005). For example, Toronto produced what is considered Canada's pioneering biotechnology firm, Allelix, founded in the early 1980s by Dr. John Evans, a former President of the University of Toronto. Both Allelix and Cangene (another early Canadian biotech firm) were spin-off firms whose initial IP emanated from research carried out at the Connaught Laboratories. Both were also financed from public agencies—the Canada Development Corporation and the Ontario Development Corporation—and Allelix also attracted important investment support from Labatt Ltd, a prominent Ontario-based brewing company.

In Montreal, the emergence of BioChem Pharma[2] (now Shire BioChem) at a time when biopharmaceuticals was a relatively young field was a watershed event in the cluster's evolution. With the successful development and subsequent success of 3TC, a breakthrough treatment for individuals living with HIV/AIDS, the firm helped put Canadian biopharmaceutical research on the global stage (Government of Canada, 1999). Aiding the entry and growth of this firm and those that followed was an increasingly receptive political and financial environment that built upon Montreal's already established capabilities in pharmaceutical research and manufacturing during this period. The creation of large public and quasi-public venture capital funds for the life sciences is also viewed as having been a significant factor spurring the growth of Montreal's biotech cluster (Kuyek, 2002; Montreal International, 2002; Niosi & Bas, 2005). Prominent examples include BioCapital, Société Innovatech du Grand Montréal, Sofinov and T2C2 Capital.

In Vancouver, the emergence of life sciences activity is closely tied to the University of British Columbia (UBC) and an early biotechnology spin-off firm, Quadra Logic Technologies (now QLT Inc.). Founded in 1981 by four UBC researchers, its emergence generated enthusiasm within and around UBC's research community and set an example for other local researchers to commercialize the IP arising from their research (Pe'er & Vertinsky, 2003). Institutional and infrastructural support from the university quickly followed this perceived success, with UBC establishing its University-Industry Liaison Office (UILO). The UBC-UILO, along with the UBC Biotechnology Laboratory (established in 1987), continue to play a significant role in the region and almost 70% of British Columbia's biotechnology firms originate from the university (PricewaterhouseCoopers, 2003).

Even though each of these examples highlights the role of a key anchor firm—MDS Nordion (Ottawa), Ocean Foods Canada (Halifax), Allelix (Toronto), BioChem Pharma (Montreal) and QLT Inc. (Vancouver), it is well worth noting that many of these anchor firms emerged as the result of public investments, either as direct spin-offs from publicly funded universities (QLT in Vancouver, BioChem Pharma in Montreal, Allelix in Toronto) or from public crown corporations (MDS Nordion in Ottawa). Again, this points to the important ways in which public investment at the national and provincial levels can assist in the development of local capabilities.

5.3.3. *The role of local industrial associations and civic entrepreneurship*

Having acknowledged the importance of public research organizations and private sector actors, it should be noted that in virtually all of the case studies, at least one industrial or civic association assumed a leadership role in support of life sciences activities in each region. In the larger urban regions, a variety of associations emerged, reflecting both the scale and variety of local life sciences activities. For example, in Toronto, different associations have emerged to represent the various sub-fields within life sciences, including the Toronto Biotechnology Initiative (TBI—now superseded by a successor organization, BioDiscovery Toronto), Medical Devices Canada (MEDEC), the Association of Ontario Medical Manufacturers (AOMM), the Health Technology Exchange (HTX) and the Canadian Generic Pharmaceutical Association. In the more specialized centres a single dominant organization emerged. Notably, the leading associations in Ottawa and Halifax claimed to represent the broader life sciences, as opposed to a narrow group of biotechnology firms.

These organizations played a number of roles including advocate and representative of common interests to local, provincial and federal governments, information and service provider to its members, and networking facilitator between various industry, government and institutional actors. For example, BC Biotech, Vancouver's main industrial association for biotechnology firms, has been described as the social "glue" that holds the cluster together. Networking events organized by BC Biotech provide opportunities for members of the small community to "meet and greet" each other (Holbrook *et al.*, 2004). Respondents in the Toronto case identified TBI as a forum where firms obtained infrastructural resources, developed local buyer–supplier relationships, accessed new clients, monitored other firms' activities and shared experiences. Also in Toronto, HTX was acknowledged for its role in facilitating alliances between local medical and assistive technology firms, as well as brokering relationships between these local firms and Ontario-based MNCs (Lowe & Gertler, 2005). The Ottawa Life Sciences Council (recently absorbed by the city's larger high-tech association OCRI) was acknowledged for its role in organizing a large annual conference known as BioNorth to showcase not only Ottawa life sciences companies but also other Canadian firms. Beginning as a regional conference, it is becoming a national forum for life sciences, increasingly attracting international participants (BioNorth, 2004).

Although it is commonplace to document the existence of such local industry and civic associations, it is fair to ask just how critical they are in determining the success and shaping the evolutionary path of local clusters. Our research suggests that these types of organizations are most important and influential when they serve as mechanisms for aligning the interests and resources of diverse stakeholders in the community, for the purpose of articulating common development goals and pursuing further resources to help achieve them (Wolfe & Gertler, 2004). Within life sciences, the degree to which these organizations were responsible for catalyzing local growth and innovation varies considerably from case to case. For example, one of the initial events that helped establish Ottawa's emerging life sciences cluster was the Ottawa-Carleton Economic Development Corporation's launch of the *Biotechnology Business Initiative* in 1988 (Kuyek, 2002). The main thrust of this initiative was to build the Ottawa Life Science Technology Park (OLSTP) near the Ottawa General Hospital and the University of Ottawa's Faculty of Medicine and Health Sciences. The 22 acre park was eventually financed and built by the Ontario Development Corporation (Kuyek, 2002). Similar to the Ottawa case, local level organizations were critical in fostering the emergence of biotechnology and life science activity in Halifax. The creation of the Biotech Working Group in 1993, followed by the Life Sciences Industry Partnership (LSIP) in 1997, helped link "scientists, business partners, universities, and government agencies [in] the biotech industry" (Brar & McLarney, 2001, p. 5). In other cases, such as Toronto, Vancouver, Montreal and Saskatoon, these organizations have played more of a supporting than a leading role.

Overall, a path-dependent analysis helps to explain the emergence, formation and development of clusters over time. In each of the cases discussed here, the critical enabling factors and triggering events were different. In some clusters, a pioneering firm sparked latent entrepreneurialism or provided credibility and “inspiration” for actors in the region (Montreal, Vancouver, Halifax, Toronto). In Saskatoon and Montreal, cluster emergence was driven by policy decisions made at the federal level to locate national laboratories in each city. Yet, in Ottawa, while local associative actors and a lead firm were important, it was an exogenous shock that served to raise the profile of life sciences activities.

6. Knowledge Flows, Learning and Cluster Dynamics

Our discussion thus far has highlighted the relative importance of local conditions and actors, alongside the broader relevance of provincial and national policy-making. This raises the important question of how the “global” fits into the picture. Recent research on learning and innovation in life sciences clusters suggests that while physical proximity is important for some forms of knowledge exchange and learning, it is also possible and beneficial for local firms to tap into non-local knowledge sources (Bathelt *et al.*, 2004; Coenen *et al.*, 2004; Owen-Smith & Powell, 2004). These local and non-local knowledge flows are critical for the ongoing viability and dynamism of the local cluster. Gertler and Levitte’s (2005) analysis of Statistics Canada’s national survey of biotechnology firms, conducted as part of this broader study, revealed that successful firms are embedded in a complex set of local and non-local relationships with other firms and institutions. Our interview-based research confirms these results and points to some particularly acute findings related to the connections that local firms have with local and non-local actors, primarily with respect to access to different sources of tacit and codified knowledge. Life science firms, especially those in Canada’s leading and established clusters, have strong local and non-local backward and forward linkages to other firms and institutions. Notwithstanding differences amongst the cases, two central themes emerge. First, the case studies offer examples of how regional institutional arrangements related to the local R&D system and venture capital contribute to structuring knowledge spillover capabilities. Second, life science firms in all six of the case studies were able to tap into both local and non-local channels of knowledge related to participating in R&D, developing and expanding market relations, and accessing human resources. Overall, our findings point unequivocally to the importance of both local and non-local sources of tacit and codified knowledge.

6.1. *The Structure of Local Venture Capital*

Our case studies revealed the important role played by venture capital in facilitating and enabling knowledge spillovers, particularly through assisting firms with the transition to commercialization. Gertler and Levitte’s (2005) study of Canadian biotechnology firms showed that these firms rely heavily on local sources of investment capital from private sources (angel investors, family and friends), and are highly likely to have spun-off from another local company or research institution at some point in their past. This observation was confirmed repeatedly during the interviews in the case studies, with the most striking case being that of QLT, which was responsible for spawning many local life science firms in Vancouver. In all of the case studies, life science firms accrued more than just financial benefits from working with venture capitalists. Venture capitalists also provided business savvy and intelligence in terms of business planning, strategy formulation and coaching. Furthermore, they facilitated networking for firms by identifying licensing opportunities and potential financial partners and acting as a communication channel for local firms.

However, the nature of venture capital investments varied substantially between places. In Montreal, venture capital firms focused primarily on the expansion stages of development whereas more than half of Toronto's venture capital investments were directed towards start-ups. Meanwhile, in Vancouver, venture capital was available largely as seed financing, with some funding available at the expansion stage (Graytek, 2005). The structure of these local venture capital markets has implications for the local circulation of knowledge. For example, Montreal's strong venture capital market has helped reinforce the cluster's focus on drug discovery by luring numerous firms from other regions beginning in the 1990s. Although venture capital firms often preferred to keep knowledge assets within the local economy, in some cases, venture capitalists have the ability and opportunity to invest in knowledge assets outside their home region. Vancouver's venture capital market provides a case in point. Vancouver-based ventures were often not able to obtain sufficient finance locally due to the small pool of local venture funds. However, as Salazar and Holbrook (2004, p. 18) observe, local venture capitalists are able to partner with non-local investors, so that "even with limited amounts of cash, their [local venture capitalists'] money acts as leverage, and more important, they can keep an eye on these firms, providing information to foreign investors". Yet, life science firms in Vancouver identified the possibility that venture capitalists would buy the local "ideas" and IP of researchers with the intention of developing them outside of the region (Penner, 2005).

6.2. *Public Research Institutions and the Local R&D System*

While venture capitalists were important, especially for assisting firms at the early stages of development and commercialization, more important in many cases was the local R&D system. Given the importance of R&D to innovation in the life sciences, it is not surprising that the presence of a well-developed local R&D system, comprising government laboratories, universities and technology transfer offices, was a common institutional feature in both diverse "megacentres" and smaller, specialized life science clusters. As previously discussed, public research institutions do not always play a catalyzing role in cluster development. However, these public research institutions were critical to anchoring life science activity to particular regions, especially because of their relationships with local firms and their role in generating talent for the local labour market.

In the cases of Montreal, Vancouver and Saskatoon, institutional leaders such as specialized centres, institutes and hospitals with strong research foci often coordinated local research activities. For example, in Vancouver, a range of regional and local actors collectively contribute to Vancouver's expertise in human health. These include the Centre for Integrated Genomics Canada (CIG), Genome BC, BC Cancer Research Centre, Canadian Genetic Diseases Network (NCE), Canadian HIV Trials Network, Michael Smith Foundation for Health Research, SARS Accelerated Vaccine Initiative and the Vancouver Coastal Health Research Institute. Furthermore, UBC's efforts through the UILO resulted in a number of spin-off firms. In Saskatoon the NRC-PBI, AAFC Saskatoon Research Centre, POS Pilot Plant and the University of Saskatchewan have agricultural-related research strengths and act to coordinate research efforts with local private sector firms. And in Montreal, the publicly funded NRC-BRI and its research universities (e.g. McGill University) co-evolved with nascent biopharmaceutical private sector efforts. These public research institutions continue to work in what is considered by outsiders as a "tripartite symbiotic relationship" with the provincial government and private sector and in this way help to shape the direction of research.

In other cases, high calibre public research centres and local universities have not only produced new research and knowledge, but have also acted as magnets to attract "star scientists" and other highly skilled workers to the region. For example, Toronto's downtown is the central location for a number of research-intensive life science institutions. The newly created MaRS centre located in Toronto's Discovery District is designed to be a convergence innovation centre providing opportunities to bring biomedical and life science researchers in contact with other diverse fields of knowledge in art, science and technology. The centre also allows for the co-location of professional service firms, technology transfer offices, research and community networking organizations and small, mid-size and large companies. This concentration of public research institutions has collectively attracted a number of top scientists and researchers, as well as the interest of venture capitalists and local start-up firms.[3]

6.3. *Human Resources and Talent Attraction*

As identified in the above discussion, public research institutions act to attract and generate an appropriately skilled and talented local labour pool. The interviews revealed that, in general, scientific and technical human resources were drawn from the local university and other public research institutes. Co-locating firms were another (often secondary) source. In some instances, sectoral crossovers in the regional labour market occurred, as in the case of Toronto's biotechnology firms benefiting from employees with pharmaceutical experience, as well as in the example of several Ottawa-based ICT entrepreneurs moving into the life sciences sector.

Efforts to attract and retain skilled labour and talent differed on the basis of the internal resources of the firm and the characteristics of the external environment (e.g. employment opportunities, quality of life, financial incentives). In the case of Toronto, additional issues emerged related to the uneven opportunities within the region. For example, some Mississauga-based firms face hurdles in attracting scientists and other potential employees from the downtown core due to real and perceived infrastructural weaknesses in areas such as transportation. In other Mississauga-based firms, the low cost of housing combined with the centrality of the region to other commuter areas acted to attract younger talent. Conversely, in the Saskatoon cluster, Phillips *et al.* (2004) found that the "thickness" of the labour market and thus, the opportunities for labour mobility and job quality, were ranked high for respondents and quality of life factors were only secondary considerations.

Despite differences in regional labour market dynamics, a common challenge amongst the six case study regions was the lack of qualified personnel locally to fill positions in more specialized areas such as regulatory affairs or senior-level management. This lack of managerial expertise is an issue that faces the biotechnology industry and is increasingly considered one of the largest limitations to growth. However, how local firms addressed issues related to attracting these highly skilled employees varied. At one end of the spectrum, Rosson and McLarney (2004) highlight how local firms in Halifax actively recruited retired executives who had settled in the area. At the other end of the spectrum, one strategy being pursued in Saskatoon included offering incentives to expatriates to return to the region (Phillips *et al.*, 2004). In the Toronto case, respondents cited both local and non-local sources and mechanisms for recruitment. Thus, although the local presence of highly skilled workers was considered important, firms also accessed non-local labour markets to recruit personnel. This corroborates the findings reported in Gertler and Levitte's (2005), which showed that one of the practices that differentiates successful biotech firms in Canada from less successful counterparts is their tendency to tap into global labour markets and networks by hiring highly qualified personnel from abroad.

In addition to tapping into global talent pools to access knowledge, life science firms also take advantage of other global flows of knowledge through the use of scientific publications and databases, by licensing their IP to foreign partners, and by licensing the IP of foreign firms for their own use. Firms develop collaborative relationships (for research or marketing purposes) that are both local and global in nature. However, as Phillips *et al.* (2004) note, there are significant interdependencies between these local and non-local knowledge flows. They suggest that "the generation and transmission of the non-codified knowledge in the regional system is the key factor holding things together. People develop skills and working relationships, which together convert bits of information into operable knowledge". In other words, local firms were able to harness these non-local sources of knowledge and, through tapping into the local tacit knowledge and skills base, firms could effectively utilize these non-local codified knowledge bases to develop value added, commercially viable products.

Overall, our findings point to the importance of both local and global knowledge flows to the innovative dynamism and performance of firms in clusters. Furthermore, these findings verify the work of Owen-Smith and Powell (2004), Bathelt *et al.* (2004) and others who emphasize the importance of non-local sources of knowledge to ongoing innovative dynamism and learning within firms in clusters. However, this does not mean that local sources of knowledge are not important but does suggest that clusters do not have to be completely self-sufficient in producing new knowledge, especially if firms are able to create value-added products based on existing knowledge.

7. Conclusions

Policymakers and scholars interested in innovation, clusters and regional economic development can draw a number of lessons from this research on the spatial organization and evolution of biotechnology and the broader life science sector in Canada. The above discussion highlights a number of common themes that emerge from our analysis of life science activity in six Canadian regions. First, our analysis highlights the importance of path dependence in cluster formation. The case studies reveal that the pre-existing strengths and initial conditions within particular places have a significant impact on the trajectory of subsequent cluster development. These initial advantages and the inherited historical legacy of particular places heavily influenced the direction of cluster development and the resulting regional specialization in certain areas of the life sciences.

Second, the dominant actor leading the process of cluster emergence and development varies across the different cases, suggesting that there is no "one way" to achieve cluster genesis. In some cases, lead firms, scientific or civic entrepreneurs played a key role in anchoring the life sciences sector in a particular place. In other cases, public research institutions such as government laboratories or universities were important in galvanizing the development of the life sciences sector. In other cases still, chance events within the local economy triggered the emergence and growth of the life sciences field. Taking a path-dependent view of the emergence and evolution of the life sciences in these six regions underscores that there is no single, universal model of cluster development within life sciences (Wolfe & Gertler, 2006). This is an important lesson for policy-makers and scholars alike. In the field of economic development, practitioners are often tempted to apply a "checklist" of necessary preconditions and policy supports (Wolfe & Gertler, 2004). Our research strongly recommends a more nuanced approach, sensitive to the distinctive features and assets of particular places.

Closely related to these first two points, our findings demonstrate the utility of taking a broader view of the life science sector rather than focusing narrowly on biotechnology. By having an inclusive definition of life sciences, we have been able to address some interesting questions about the relative importance of specialization or diversity of life science activity within a particular region. There are a number of different paths to cluster development, with some places developing one or more particular niches within the life sciences, whereas other regions host a diverse range of life science activities. Each of these paths to cluster development can lead to positive outcomes, as well as a number of drawbacks. The case of Toronto stands out as an example where the strength of its highly diverse life science cluster is not adequately captured using traditional metrics such as patents and patent citations, firm spin-offs, and levels of venture capital and R&D investments. Moreover, the diversity of the regional economy in this case has provided distinctive opportunities for the combination of technologies and competencies from different knowledge bases, leading to high levels of innovation within the broader biomedical sphere. Yet, this diversity of activities can present challenges in the development of critical mass in any single area of concentration, and also makes it more difficult to develop visibility, a coherent identity and profile, both locally and globally (see Lowe & Gertler, 2008). However, compared to places with a high degree of specialization in particular areas of the life sciences, diverse life science clusters are less susceptible to market volatility. Specialized life sciences clusters such as those observed in Montreal or Saskatoon may experience high returns if these places develop expertise in high-growth areas, but are also subject to higher levels of risk if key markets decline, or dominant firms and/or their core technologies fail.

Fourth, our research demonstrates both the direct and indirect ways that public policy influences the evolution of the life science innovation system, as well as pointing to the multi-level nature of this governance. It is clear that policy- and decision-making at the federal and provincial levels have had a particularly strong influence on the evolution of the life sciences in different regional contexts. This occurs through a number of mechanisms. First, investments in biotechnology-related research labs in particular locations have been important for providing local strengths in niches of the life sciences. For example, Saskatoon's strengths in agricultural and food-related biotechnologies and Montreal's strengths in biopharmaceuticals were greatly leveraged by the presence of federal laboratories. Second, provincial legislation and expenditures on health care have provided substantially different contexts for the development of the life sciences in different regions of the country. Finally, at the local level, industrial associations, technology transfer offices and local economic development offices often play an important role in assisting firms by providing support services, networking opportunities, and other forms of direct and indirect assistance.

The findings of our research reveal that, contrary to the conventional wisdom emerging in the literature on biotechnology and life sciences clusters, universities and government laboratories have not always played a leading role in the formation and development of biotechnology and life science clusters. Moreover, these public research institutions perform a wider range of important roles than is conventionally acknowledged within the literature on life science clusters. While universities and government laboratories have often been critical in building a local knowledge base through the research that they host, their impact in this regard varies substantially from case to case. In some cases, these institutions have taken a relatively passive stance, while in others they have been instrumental in new firm formation and co-ordination of R&D efforts through aggressive partnership, commercialization, and technology transfer programmes.

Important as these activities have been, they have likely been overshadowed by the critically important role these same institutions play in producing highly educated talent, which provides a powerful local anchor for life science activity in the region (see also Bramwell & Wolfe, 2008; Gertler & Vinodrai, 2005). Finally, these institutions also act as important agents in attracting scientific talent from other regions and countries. Once ensconced in the local labour market, this talent further sustains the growth and innovative capacity of the life science cluster through their mobility between firms, and through the collaborative research and networking activities they promote. These activities facilitate the circulation, sharing and joint production of knowledge locally, while also serving to combine knowledge from local and non-local sources (see Phillips *et al.*, 2004). In this way, our findings confirm the findings of Owen-Smith and Powell (2004), Bathelt *et al.* (2004) and Coenen *et al.* (2004), which emphasize the complementary nature of local and non-local sources of knowledge in underpinning the innovative dynamism of firms in clusters. From this perspective, those promoting the development of clusters should not adhere to misconceived notions of self-sufficiency when it comes to producing the knowledge on which life science innovation rests.

Acknowledgement

An earlier version of this paper was presented at the Annual Meeting of the Innovation Systems Research Network, Toronto, Canada, 5–6 May 2005. The authors wish to acknowledge the financial support of the Social Sciences and Humanities Research Council of Canada through its Major Collaborative Research Initiatives Program. The authors also wish to acknowledge the contributions of fellow investigators studying life science clusters within the Innovation Systems Research Network, whose work we have summarized here: Adam Holbrook, Jorge Niosi, Peter Phillips and Philip Rosson. Finally, the authors thank Uyen Quach, Nichola Lowe, David Wolfe and Tijs Creutzberg for their critical comments and suggestions on earlier drafts of this paper.

Notes

1. There are several examples of Ottawa's high-profile ICT entrepreneurs moving into life science ventures. For example, Rod Bryden, co-founder and former CEO of SHL Systemhouse, became the Chairman and CEO of WorldHeart Corporation and Jan Kaminski, former President and CEO of FastLane Technologies, became the President and CEO of Ionalytics Corporation.
2. Motivated in the 1980s to "work for himself" and exploit world class research in Canada (and especially Montreal), Dr. Francesco Bellini co-founded the company with a group of other researchers from McGill University (Nicholson, 2004). Bellini continues to play an important role in Montreal and has helped several other firms in the region following the acquisition of BioChem Pharma by UK-based Shire Pharmaceutical. More recently, he donated $10 million to McGill University to establish the Francesco Bellini Life Sciences Building.
3. For example, the Ontario Cancer Institute at Princess Margaret Hospital recently recruited Dr. Ben Neel, a star scientist from Boston. His decision to relocate was based on the type of research taking place at the institution in areas such as stem cell research, as well as the willingness of funding agencies to support independent research in contrast to the "picking winners" strategy being pursued in the USA (see Reinhart, 2006).

References

Asheim, B. T. & Gertler, M. S. (2005) The geography of innovation: Regional innovation systems, J. Fagerberg, D.C. Mowery & R.R. Nelson (Eds), *The Oxford Handbook of Innovation*, pp. 291–317 (Oxford: Oxford University Press).

Asheim, B. T., Cooke, P. & Martin, R. (Eds) (2006) The rise of the cluster concept in regional analysis and policy, *Clusters and Regional Development: Critical Reflections and Explorations*, pp. 1–29 (London: Routledge).

Bathelt, H., Malmberg, A. & Maskell, P. (2004) Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation, *Progress in Human Geography*, 28(1), pp. 31–56.

BioNova (2004) *Imagine: A Strategy to Grow the Nova Scotia Life Science Industry* (Halifax, NS: BioNova).

BioNorth (2004) *History*, Available at http://www.bionorth.ca/about/history.html (accessed 15 December 2008).

BIOTECanada (2004) *Biotech in Canada—an overview*.

Biotechnology Research Institute (2004). *Annual Report 2003–2004*, National Research Council of Canada Montreal.

Bramwell, A. & Wolfe, D. A. (2008) Universities and regional economic development: The entrepreneurial University of Waterloo, *Research Policy*, 37(8), pp. 1175–1187.

Brar, B. & McLarney, C. (2001) Poised for success? An analysis of the Halifax biotechnology cluster (Halifax Nova Scotia: Centre for International Trade and Transportation, Dalhousie University), Discussion Paper 187.

Buist, M. (2004) Fourth largest biotechnology cluster in North America, M. de Reus (Ed.), *Toronto: Business & Market Guide 2004*, pp. 67–73.

Casper, S. & Murray, F. (2005) Careers and clusters: Analyzing the career network dynamics of biotechnology clusters, *Journal of Engineering Technology Management*, 22(1/2), pp. 51–74.

Christensen, J. (2003) Introduction: The industrial dynamics of biotechnology: New insights and new agendas, *Industry and Innovation*, 10(3), pp. 223–230.

Coenen, L., Moodysson, J. & Asheim, B. T. (2004) Nodes, networks and proximities: On the knowledge dynamics of the Medicon Valley biotech cluster, *European Planning Studies*, 12(7), pp. 1003–1018.

Cooke, P. (2001) New economy innovation systems: Biotechnology in Europe and the USA, *Industry and Innovation*, 8(3), pp. 267–289.

Cooke, P. (2003) The evolution of biotechnology in three continents: Schumpeterian or Penrosian? *European Planning Studies*, 11(7), pp. 757–763.

Cooke, P. (2005) Rational drug design, the knowledge value chain and bioscience megacentres, *Cambridge Journal of Economics*, 29(3), pp. 325–341.

Cooke, P. (2007) *Growth Cultures: The Global Bioeconomy and its Bioregions* (London: Routledge).

Cooke, P. (2008) Cleantech and an analysis of the platform nature of life sciences: Further reflections upon platform policies, *European Planning Studies*, 16(3), pp. 375–393.

Cortright, J. & Mayer, H. (2002) *Signs of Life: The Growth of Biotechnology Centers in the US* (Washington, DC: Center on Urban and Metropolitan Policy, The Brookings Institution).

Duffy, A. A. (2000) No place like home, *Times Colonist* (Victoria, BC, August 30, p. D1).

Ernst & Young (2005a) *Beyond Borders. The Global Biotechnology Report 2005*.

Ernst & Young (2005b) *Product Success and Strong Financials Drive Biotech Industry's Maturation According to Ernst & Young's 2005 Global Biotechnology Report*, Press Release, June 1. Available at: http://www.bioresearchonline.com/article.mvc/Product-Success-And-Strong-Financials-Drive-B-0001

Feldman, M. P. (2000a) Location and innovation: The new economic geography of innovation, spillovers, and agglomeration, G. L. Clark, M. P. Feldman & M. S. Gertler (Eds), *The Oxford Handbook of Economic Geography*, pp. 373–394 (Oxford: Oxford University Press).

Feldman, M. P. (2000b) Where science comes to life: University bioscience, commercial spin-offs, and regional economic development, *Journal of Comparative Policy Analysis: Research and Practice*, 2(3), pp. 345–361.

Feldman, M. P. (2003) The locational dynamics of the US biotech industry: Knowledge externalities and the anchor hypothesis, *Industry and Innovation*, 10(3), pp. 311–328.

Feldman, M. P. & Francis, J. (2003) Fortune favors the prepared region: The case of entrepreneurship and the Capitol Region biotechnology cluster, *European Planning Studies*, 11(7), pp. 765–788.

Feldman, M. P., Francis, J. & Bercovitz, J. (2005) Creating a cluster while building a firm: Entrepreneurs and the formation of industrial clusters, *Regional Studies*, 39(1), pp. 129–141.

Gertler, M. S. & Levitte, Y. M. (2005) Local nodes in global networks: The geography of knowledge flows in biotechnology innovations, *Industry and Innovation*, 12(4), pp. 487–507.

Gertler, M. S. & Vinodrai, T. (2005) Anchors of creativity: How do public universities create competitive and cohesive communities? F. Iacobucci & C. Tuohy (Eds), *Taking Public Universities Seriously*, pp. 293–315 (Toronto: University of Toronto Press).

Government of Canada (1999) *3TC: confronting HIV/AIDS, Visionaries: Canada's Triumphs, Canada Heirloom Series Volume 6*, Available at http://epe.lac-bac.gc.ca/100/205/301/ic/cdc/heirloom_series/volume6/volume6.htm (accessed 15 December 2008).

Graytek (2005) *ICT/Life Sciences Converging Technologies Cluster Study: A Comparative Study of the Information and Communications, Life Sciences, and Converging Next Generation Technology Clusters in Vancouver, Toronto, Montreal and Ottawa*, Report prepared for ICT and Life Sciences Branches of Industry Canada and the National Research Council.

Holbrook, J. A., Salazar, M., Crowden, N., Reibling, S., Warfield, K. & Weiner, N. (2004) The biotech cluster in Vancouver, D. A. Wolfe & M. Lucas (Eds), *Clusters in a Cold Climate: Innovation Dynamics in a Diverse Economy*, pp. 95–112 (Montreal: McGill-Queen's University Press).

Industry Canada (2005) *Biotechnology in Canada: A Cities Perspective* (Ottawa: Industry Canada Life Sciences Branch).

Kuyek, D. (2002) *The Real Board of Directors: The Construction of Biotechnology Policy in Canada, 1980–2002* (Sorrento, BC: The Ram's Horn).

Langford, C., Wood, J. & Phillips, P. (2002) *Global science in Western Canadian clusters: Wireless, global positioning, and agricultural biotechnology*, Paper presented at the Triple Helix Conference, Oslo, Norway, 6–9 November.

Legge, P. (2003) *Life Sciences Industry in B.C. Letter to the Honorable Gordon Campbell. Vancouver Board of Trade*.

Lowe, N. J. & Gertler, M. S. (2005) Diversity and the evolution of a life-science innovation system: The Toronto region in comparative perspective, D. A. Wolfe & M. Lucas (Eds), *Global Networks and Local Linkages: The Paradox of Cluster Development in an Open Economy*, pp. 25–56 (Montreal and Kingston: McGill-Queen's University Press).

Lowe, N. J. & Gertler, M. S. (2008) Building on diversity: Institutional foundations of hybrid strategies in Toronto's life sciences complex, *Regional Studies*, 42(9), pp. 1–15.

McKarney, L. (2001) Under one roof, Part 4: Biotech in the Prairies, *Science*, November 30.

Mihlar, F. (2003) Here's a shiny lure for biotech dollars, *Vancouver Sun*, February 24.

Montreal International (2002, April) *Accelerating the Development of the Life Sciences Cluster: 2002–2010 Action Plan for Greater Montreal* (Montreal: Quebec).

Montreal International (2004) *Life Science: The Metro Montreal Cluster 2003, Strategic Profile of a Success Story*, Available at http://www.montrealinternational.com/docs/Profil_SciencesVie_en_2003.pdf (accessed 15 December 2008).

Niosi, J. & Bas, T. G. (2003) Biotechnology megacentres: Montreal and Toronto regional innovation systems, *European Planning Studies*, 11(7), pp. 789–804.

Nicholson, P. (2004) Ambitious biopharma, *Bioscience World*, February 16.

Niosi, J. & Bas, T. G. (2004) Canadian biotechnology policy: Designing incentives for a new technology, *Environment and Planning C: Government and Policy*, 22(2), pp. 233–248.

Niosi, J. & Bas, T. G. (2005) Biotechnology, *Canada's Regional Innovation Systems: The Science-Based Industries*, pp. 29–60 (Montreal: McGill-Queen's University Press, Jorge Niosi with the collaboration of Tomas Gabriel Bas and Majlinda Zhegu.

OECD (2002) *Statistical definition of biotechnology*, Available at http://www.oecd.org/document/42/0,3343,en_2649_34537_1933994_1_1_1_37437.00.html (accessed 14 December 2008).

OEOBC/OLSC (Ottawa and Eastern Ontario Biotech Cluster/Ottawa Life Science Council) (2004) *Biotechnology Cluster Innovation Program: Part 2*, Biotechnology Cluster Strategy. BCIP Report, March 23.

OLSC/OCRI (Ottawa Life Sciences Council and Ottawa Centre for Research and Innovation) (2002) *Ottawa's Technology Convergence Opportunity*.

Owen-Smith, J. & Powell, W. W. (2004) Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community, *Organization Science*, 15(1), pp. 5–21.

Pe'er, A. & Vertinsky, I. (2003, August) *Evaluation of British Columbia's Life Sciences Cluster* (British Columbia: Prepared for the Premier Technology Council).

Penner, D. (2005) Vancouver to surpass Toronto as biotech epicentre, *Vancouver Sun*, March 31.

Phillips, P. W. B., Parchewski, J., Procyshyn, T., Ryan, C., Karwandy, J. & Kihlber, J. (2004) *Agricultural and Life-Science Clusters in Canada: An Empirical and Policy Analysis*, AAFC Study of the Saskatoon Cluster Final Project Report, 30 March.

Porter, M. E. (2000) Locations, clusters, and company strategy, G. L. Clark, M. P. Feldman & M. S. Gertler (Eds), *The Oxford Handbook of Economic Geography*, pp. 253–274 (Oxford: Oxford University Press).

Prevezer, M. (2001) Ingredients in the early development of the US biotechnology industry, *Small Business Economics*, 17(1), pp. 17–29.

PricewaterhouseCoopers LLP (2003) *An Integrated Strategy For British Columbia's Technology Clusters*, White Paper.

Queenton, J. & Niosi, J. (2003) Bioscientists and biotechnology: A Canadian study. Paper presented to the Annual Meeting of the Innovation Systems Research Network, Ottawa, 1–2 May.

Reinhart, D. (2006) Cancer institute gains top scientist, *Globe & Mail*, June 14.

Rosiello, A. (2008) Rethinking innovation systems in life sciences: Implications for regional and innovation policy, *European Planning Studies*, 16(3), pp. 329–335.

Rosson, P. & McLarney, C. (2004) Biotechnology companies and clustering in Nova Scotia, D. A. Wolfe & M. Lucas (Eds), *Clusters in a Cold Climate: Innovation Dynamics in a Diverse Economy*, pp. 73–94 (Montreal, QC: McGill-Queen's University Press).

Salazar, M. & Holbrook, A. (2004) In search of impact and outcome indicators based on Vancouver biotechnology cluster studies, presented at the colloquium on Measuring the Impacts of Science, Montreal, Quebec, June 17–18.

Science-Metrix (2005) *Scan of Canadian Strengths in Biotechnology* (Montreal, Quebec: Prepared for the National Research Council Canada Research Program Support Office).

Spencer, G. & Vinodrai, T. (2005) An inductive approach to mapping and measuring clusters in Canada, Paper presented to the Annual Meeting, ISRN, Toronto, Ontario, 6 May.

Statistics Canada. (2003) *Features of Canadian Biotechnology Innovative Firms: Results from the Biotechnology Use and Development Survey—2001*. Science, Innovation and Electronic Information Division Working Papers, Statistics Canada, Ottawa, Ontari. Cat. No. 88F0006XIE2003005.

Statistics Canada. (2004) *Trends in Canadian Biotechnology Activity: 1997–2001*. Science, Innovation and Electronic Information Division Working Papers, Statistics Canada, Ottawa, Ontario. Cat. No: 88F0006XIE2004017.

Statistics Canada. (2005a) *Overview of the Biotechnology Use and Development Survey 2003*. Science, Innovation and Electronic Information Division Working Papers, Statistics Canada, Ottawa, Ontario. Catalogue No. 88F0006XIE.

Statistics Canada. (2005b) Biotechnology scientific activities in federal government departments and agencies, 2003–2004, *Science Bulletin*, 29(3), Science, Innovation and Electronic Information Division, Statistics Canada, Ottawa, Ontario, Catalogue No. 88001XIE.

Thorsteinsdóttir, H., Quach, U., Martin, D. K., Daar, A. S. & Singer, P. A. (2004) Conclusion: Promoting health biotechnology innovation in developing countries, *Nature Biotechnology*, 22(125), pp. D48–D52.

Traore, N. (2006) Networks and rapid technological change: novel evidence from the Canadian biotechnology industry, *Industry and Innovation*, 13(1), pp. 41–68.

VEDC, BC Biotech & Discovery Parks Inc (2002, October). *Vancouver: A North American Biotechnology Centre* (Vancouver, BC: BC Biotech, and Discovery Parks Inc), Study conducted by Vancouver Economic Development Commission.

Wolfe, D. A. & Gertler, M. S. (2004) Clusters from the inside and out: Local dynamics and global linkages, *Urban Studies*, 41(5–6), pp. 1071–1093.

Wolfe, D. A. & Gertler, M. S. (2006) Local antecedents and trigger events: Policy implications of path dependence for cluster formation, P. Braunerhjelm & M. Feldman (Eds), *Cluster Genesis: Technology-Based Industrial Development*, pp. 243–263 (Oxford: Oxford University Press).

Zucker, L. & Darby, M. (1998) Intellectual human capital and the birth of US biotechnology enterprises, *American Economic Review*, 88(1), pp. 290–306.