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Regional Clusters in a Global Industry: ICT Clusters in Canada

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Abstract *This paper reports the results of a 5-year study of eight information and communication technology clusters across Canada. It summarizes the key findings from the individual cases and poses several questions: What are the critical factors that contributed to the emergence and development of the individual clusters in their specific locations? What is the relative importance of local versus non-local factors in supporting the overall dynamism of the clusters? And what are the most important factors that contribute to the ongoing competitiveness of the clusters? In conclusion, it summarizes the import of our findings for the cluster literature in general and sets out the main policy implications.*

Introduction

No industry or technology sector is more central to the development of the digital economy than the information and communication technology (ICT) sector. Its emergence as the leading growth sector since the 1970s has had a major impact on virtually every sector of the economy. Information and communication technologies constitute a transformative technology, comparable to the core technologies in earlier industrial revolutions (Freeman & Louçã, 2001). The core innovation which lies at the heart of this revolution is the conversion of mechanical, electric and electro-mechanical systems to electronic ones, combined with a relentless trend towards the miniaturization of components that allows for the rapid diffusion and adoption of these components in an ever-expanding range of electronic goods. A key feature of the sector is the rapid rate of innovation and the corresponding acceleration of productivity increases in the industries producing the microelectronic components used in virtually all ICT applications (Castells, 1996, pp. 31–32; OECD, 2001, p. 21).

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Despite the growing integration of individual economies into a global one, the geography of production in the new economy is marked by a "paradoxical consequence of globalization"—the simultaneous growth in importance of the locality as a site for innovation (Acs *et al.*, 1996, p. 340). The production paradigm of the new economy, with its emphasis on knowledge and creativity, is highly dependent on localized, or regionally based, innovation (Morgan, 2004). Innovative capabilities are often sustained through regional clusters that share a common base of knowledge and the additions to that knowledge base. The dramatic growth of Silicon Valley in the last decades of the twentieth century paralleled the emergence of the ICT paradigm and sparked a dramatic interest in the process of cluster development. This interest has been prompted, in part, by the ability of Silicon Valley to reinvent itself through successive waves of innovation; and, in part, by the increasing efforts of other regions and locales to emulate the Silicon Valley model (Kenney, 2000; Lee *et al.*, 2000).

A growing number of clusters around the globe all claim direct lineage to the original model in northern California, an assumption which is strongly supported in much of the literature on emerging ICT clusters (Bresnahan & Gambardella, 2004; Castells & Hall, 1994; Miller & Coté, 1987; Rosenberg, 2002). In contrast to this assumption, several of the cases examined in this study emerged as information and telecommunication clusters in the same period or shortly after Silicon Valley. This raises the question of whether they followed the same trajectory that contributed to the growth of Silicon Valley or whether they were the product of a different combination of factors anchored in the specific character of their individual locations. In this respect, we concur with the key questions posed in a recent comparative study of ICT clusters: how did these later cases emerge as centres of ICT-related growth and what factors account for their ability to subsequently build on their initial success (Bresnahan *et al.*, 2001, p. 837).

This paper reports the results of a 5-year study of eight ICT clusters across Canada undertaken as part of the Innovation Systems Research Network's (ISRN) national study of industrial clusters (Holbrook & Wolfe, 2005; Wolfe *et al.*, 2005). Each case study used a consistent methodology to examine whether the co-location of firms, financial and legal services, research and training institutes, business and civic associations, and public support organizations formed the basis for a viable cluster that could sustain endogenous innovation and industry growth (Wolfe & Gertler, 2004). Researchers identified the actors who provided key inputs to the industry, served as a market for key outputs, and facilitated interaction within the region; they then identified linkages between these actors, including both formal participation in supply chains, research consortia, and civic associations, and informal relationships established through shared employment, educational histories and personal exchanges between key individuals. Finally, they gauged how these interactions contributed to the capacity of individual firms and the overall cluster to remain locally vibrant and globally competitive. The paper summarizes the key findings from the individual cases and poses several questions: What are the critical factors that contributed to the emergence and development of the individual clusters in their specific locations? What is the relative importance of local versus non-local factors in supporting the overall dynamism of the clusters? And what are the most important factors that contribute to the ongoing competitiveness of the clusters? In conclusion, we examine the import of our findings for the cluster literature in general and set out the main policy implications.

The ICT Sector and Clusters in Canada

The ICT sector in Canada is a large and dynamic sector, with a substantial export orientation, but one which consists overwhelmingly of small companies. Of the almost 32,000 companies comprising the sector in 2005, 80% employed only one to nine people. Conversely, only 2.5% of the companies in the sector were classified as medium to large in size and there were only 120 companies with over 500 employees. Canadian ICT firms are also small relative to the global industry, with only two firms consistently ranking among the top global ICT firms. Total employment in the ICT sector was 572,000 in 2006, accounting for 3.5% of all Canadian employment in that year. While overall ICT employment has risen since 2000, employment in the manufacturing sector has fallen by 24%. Total ICT sector revenues were $140.5 billion (Canadian) in 2005, of which over 70% was accounted for by firms in Ontario and Quebec. Despite the fact that the ICT sector as a whole accounts for 5.9% of total Canadian GDP, it is the largest R&D spender in the economy by a wide margin. R&D spending for the ICT sector for 2006 amounted to $5.7 billion, which is still below the sectoral peak of $6.6 billion reached in 2001. ICT sector R&D accounted for 39% of total private sector R&D, which is well below the 49% share that it represented in 2000 (ICT Branch Industry Canada, 2007).

The ISRN research project employed several techniques to investigate the cluster dynamics of the individual cases. In addition to the case study methodology described above, project researchers created a statistical database and developed a unique definition of Canadian clusters using four digit level NAICS codes (Spencer & Vinodrai, 2005). Indicators from the ISRN database are used to map the relative size and degree of concentration of the eight ICT clusters (Table 1).

The individual case studies of internal cluster dynamics focused on subsectors of the overall cluster. The eight case studies included: ICT in Toronto (Britton, 2003, 2004; Creutzberg, 2005); telecommunications and photonics in Ottawa (Brouard *et al.*, 2005; Chamberlin & de la Mothe, 2003); ICT in Waterloo (Bramwell & Wolfe, 2008; Bramwell *et al.*, 2008; Nelles *et al.*, 2005); ICT in New Brunswick (Davis & Schaefer, 2003; Davis & Sun, 2006) and Cape Breton (Johnstone & Haddow, 2003); photonics in Quebec City (Kéroack *et al.*, 2004; Ouimet *et al.*, 2007); and wireless in Calgary and Vancouver (Langford & Wood, 2005; Langford *et al.*, 2003). The individual cases differ considerably in age, size, firm composition, technological focus and maturity. While the case studies account for a large share of Canada's ICT sector, they do not cover all of the ICT activities in a given region; rather, they highlight key factors in the formation and growth of clusters.

The Greater Toronto Area is home to the country's largest ICT cluster and the largest among our cases. A 2004 study on Toronto's ICT industry placed the region as the third largest ICT cluster in North America, after San Francisco and New York. It includes nearly 3000 establishments and employed 212,000 people in both services and manufacturing (Table 1). It includes the head offices of many foreign multinationals and domestic firms, including IBM Canada, Celestica, Hewlett Packard Canada and Microsoft (E&B Data, 2004; The Impact Group, 2006, pp. 15–18). The next two largest cases are located in Vancouver and Ottawa, but with radically different distributions of employment between manufacturing and services (Table 1). The Vancouver case study focused on the wireless subsector. A survey of the wireless cluster identified 121 firms, most of whom had been involved in the wireless industry for less than 5 years and most of

Table 1. Comparison of ICT (manufacturing and services) clusters in Canada

	Cape Breton	New Brunswick	Quebec City	Ottawa/Gatineau	Toronto	Waterloo	Calgary	Vancouver
Employment								
Services	1185	11,925	15,410	45,580	143,785	11,615	31,420	60,255
Manufacturing	110	1730	4660	27,880	68,460	7165	10,405	15,215
Total	1295	13,255	20,070	73,460	212,245	18,780	41,825	75,470
Establishments								
Services	37	337	542	2585	8115	400	2208	2411
Manufacturing	10	77	192	333	1968	138	397	842
Total	47	414	734	2918	10,083	538	2605	3253
Location quotient								
Services	0.69	0.81	1.06	1.93	1.41	1.25	1.38	1.42
Manufacturing	0.17	0.30	0.83	3.05	1.74	2.00	1.18	0.93
Total	0.54	0.67	1.00	2.24	1.50	1.46	1.32	1.28
Average annual income								
Services	$32,976	$37,285	$34,202	$52,617	$50,895	$43,349	$47,051	$45,585
Manufacturing	n/a	$33,944	$39,681	$57,615	$49,281	$43,648	$48,155	$50,015

Source: ISRN Indicators, Database, Statistics Canada.

whose revenues came from exports to Europe and the USA (Langford & Wood, 2005). Employment in the Ottawa cluster was concentrated historically in two key segments, telecommunications and photonics, but this has fallen since 2001 (Brouard *et al.*, 2005). The concentration of the Ottawa cluster in ICT manufacturing activities is reflected in the high location quotient for that subsector, as well as its high level of average annual income (Table 1).

The Calgary cluster is next overall, with a stronger concentration in services than manufacturing (Table 1). The case study focused on the wireless subsector, which is a relatively young cluster with well over 100 firms—more than 50% of which have been launched since 1995—and 12,000 employees (Langford *et al.*, 2003). Next in size is the Waterloo ICT cluster, comprised of a diverse mix of firms in software, wireless technologies and advanced manufacturing. The cluster is distinguished by its relatively even distribution between manufacturing and services, with the second highest location quotient in manufacturing (Table 1), reflecting the historically strong base of manufacturing activity in the region (Nelles *et al.*, 2005). The Quebec City cluster, while slightly larger overall than the Waterloo cluster has a much smaller concentration in manufacturing, as reflected in its location quotient (Table 1). The case study focused on the small, highly innovative, and research-intensive photonics cluster. In 2003 it comprised just 22 firms, with three major training centres, three research centres, and a small number of venture capital and other support organizations (Kéroack *et al.*, 2004; Ouimet *et al.*, 2007).

In New Brunswick, the case study included the province's three largest urban centres, Saint John, Moncton and Fredericton, which combined, still ranked behind the urban centres in central and western Canada (Table 1). The cluster consists of telecommunication firms, software developers, IT services, multimedia and IT-based advanced training, most of whom are small and locally owned (Davis & Schaefer, 2003). The nascent ICT cluster in Cape Breton, Nova Scotia was targeted by provincial and federal authorities as a means of generating new economic activity in a declining industrial region. It differs from the other case studies in the limited success achieved. Most of the ICT employment in the region is in call centres and data entry firms, which are partially attracted by low labour and business costs. The cluster remains relatively weak and at the time the study was conducted, had not achieved a sustained development trajectory (Johnstone & Haddow, 2003).

Cluster Origins and Path Dependency

The cluster literature has focused a great deal of attention on the forces that lie behind cluster formation and growth. The concepts of path dependency and lock-in imply that a region's trajectory is determined by a confluence of endowment factors and trigger events that stimulate the process of cluster formation (Wolfe & Gertler, 2006). Bresnahan *et al.* (2001, p. 842) believe that "(s)tarting a cluster involves, first, building the economic fundamentals for an industry or technology, and second, finding the spark of entrepreneurship to get it going". In a broad comparative study of a number of emerging regions attempting to emulate Silicon Valley, they examined a range of critical factors that contributed to cluster success and concluded that the key factor in the cases studied was the low opportunity cost of gaining access to ready supplies of skilled human capital that attracted managerial talent and entrepreneurs into the cluster. This view concurs with the perspective of Feldman *et al.* who provide a descriptive model which places entrepreneurship at the

centre of the process. Entrepreneurs act as the key agents who build upon the existing base of institutional assets that provide the local antecedents for cluster formation. Entrepreneurial activity stimulates the development of industrial clusters over time in a series of phases (Feldman *et al.*, 2005).

There is a common theme linking the clusters in our study; in each case, early commercial success came from exploiting the local knowledge base to commercialize new products and services. Some innovations related to the development of new technologies, such as the development of the CO_2 laser in Quebec City and new computer software in Waterloo, while others related to increasing market demands for existing technology, such as the need for wireless communication in Alberta's oil and gas industry and the New Brunswick government's support for the decision to create a provincial broadband network. The early success of cluster firms depended upon their ability to exploit both local and global knowledge sources to develop, market, and sell innovations to external customers. The lead anchor firms were able to draw upon existing capital, skilled local labour markets and exploit their existing or new linkages with customers to commercialize their products. Some chose to spin-off new firms to develop products or actively promote the growth of new firms through an "affiliates" programme, because the new technologies lay outside their core capabilities. The initial success of an anchor firm or startup often provided a demonstration effect for other potential entrepreneurs in the cluster to emulate their success. The growth of both the lead anchor firms and the gradual birth of additional new firms influenced the organizational structure of the clusters.

The Ottawa case provides a classic illustration of this process. The original decision by Northern Electric in the late-1950s to establish a research facility in the region was made after a judicial decision in the US cut off its ready access to patents from the Western Electric Co. Its purchase of a substantial tract of land on the outskirts of Ottawa as the future home of Bell Northern Research (BNR), largely because of the concentration of federal government laboratories in the nation's capital, created a steady stream of industrial engineers, researchers and managers moving into the region. Many of the leading entrepreneurs in the Ottawa telecommunications and photonics cluster began their careers as researchers for BNR or its failed subsidiary, Microsystems International Ltd (MIL). Both technical and entrepreneurial talent left Nortel over the years to form new firms in the region. The demise of MIL was significant for the cluster in two respects—it attracted a large number of highly skilled IT scientists and engineers to the Ottawa area in the 1970s and its closure released a significant number of skilled workers into the regional economy, many of whom went on to found, or work for, new firms. More than 20 local startups emerged from the collapse of MIL, including some of the cluster's leading firms, such as Mitel, Mosaid and Calian (Chamberlin & de la Mothe, 2003; Harrison *et al.*, 2004).

The initial driving force behind Calgary's wireless cluster was the perceived need for improved communications technology to facilitate exploration and drilling for petroleum and natural gas in the province's diverse geography. A key factor was the creation of NovAtel in 1982, jointly by Alberta Government Telephones (AGT) and Nova Corporation, which developed the first wireless telephone network in North America. Many of the people working at later startups traced their roots back to their formative period as employees of NovAtel (Langford *et al.*, 2003). The Vancouver wireless cluster traces its roots to three firms that emerged in the late-1960s and mid-1970s, who were innovators in mobile data technologies: Mobile Data International, Glenayre and MPR-Teltech. These firms established a critical mass of wireless expertise in the region and spunoff

most of the firms that now populate the cluster. Their initial success and leading technology made them attractive takeover targets for larger multinationals in the 1990s. The subsequent restructuring resulted in the spinning off of numerous firms that populate the cluster and draw upon the talent pool that remained in Vancouver after the anchor firms' demise (Langford & Wood, 2005).

The New Brunswick cluster took shape in the mid-1980s after the provincial government identified ICT as a sector with potential to create economic growth in the region. NBTel, the provincial telecom provider and lead anchor firm invested in digital infrastructure and developed a number of leading edge technologies. The provincial government also upgraded the province's ICT infrastructure and improved citizen accessibility to the Internet, expanding the local market for ICT products and services. The cluster's subsequent development was heavily impacted when NBTel merged with three other provincial telephone companies in Atlantic Canada to form Aliant and reduced its commitment to product innovation in the region (Davis & Schaefer, 2003).

In those cases where a lead anchor firm was absent, such as Quebec and Waterloo, universities and research institutes played a more instrumental role in the cluster's formation. A key event in the formation of the Quebec photonics cluster was the discovery of the CO_2 laser in 1960 at the Defence Research and Development Canada Laboratories, which led to the build up of local expertise in photonics. This expertise was further embedded with the creation of two research institutes based on industry–university–government partnerships in the mid- and late-1980s. The transition from research to industrial application began in the early 1980s with the creation of many of the photonics cluster's leading firms: Exfo, ABB Bomem and Gentec (Kéroach *et al.*, 2004). The ICT cluster in Waterloo grew out of a strong industrial base in advanced manufacturing, a local university focused on engineering, math and computer science, and a civic culture that supported linkages between firms and between firms and public institutions, particularly universities. Waterloo's first ICT firms were created in the early 1970s when a number of firms began developing software and hardware to support networking and communications applications. Two of the early firms, WATCOM and Dantec Electronic, were both spunoff from the University of Waterloo in 1974. The emergence of these early spin-offs had a strong demonstration effect for subsequent local startups in the 1980s and 1990s, such as Open Text and Research in Motion (Nelles *et al.*, 2005).

The origins of Toronto's ICT cluster reflects the intersection of strategic policies adopted by the federal government, as well as the attractiveness of the GTA as a site for the Canadian operations of large US multinational corporations. Early decisions by the Defence Department supported the academic ambitions of the University of Toronto to expand in the emerging area of computer technology and laid the basis for the emergence of academic expertise in the field. By the 1970s, the GTA was home to the national offices of leading multinationals, such as Fairchild Semiconductor, Canadian Marconi, Canadian General Electric, and Canadian Westinghouse and Control Data Corporation. Federal programmes introduced in the 1970s encouraged them to extend their R&D efforts in computer technology, further expanding the technological capabilities of cluster firms. Another federal programme introduced in the 1980s to support university research centres provided the research expertise at the University of Toronto, which supplied the emerging graphics chip firm, ATI Technologies, with some of its first microchip designs, in effect operating as the research arm for what became the GTA's largest semiconductor firm before it was purchased by AMD (Creutzberg, 2005).

In each of our cases, the antecedent conditions for cluster formation were laid by the presence of a strong research base, either in lead anchor firms or public sector institutions. The demonstration effect of the lead anchor firms or new startups exploiting emerging technological niches provided the spark to stimulate further entrepreneurial activity. As the clusters grew, new firms emerged specializing in niche market segments, complementing and supporting the work of other local firms. Conversely, the creation and attraction of new firms increases internal competition that can increase rivalry between firms within the cluster; some of the firms that move into the region may be direct competitors to indigenous firms both for business and employees. Some multinationals enter a cluster to tap into the local resources of knowledge and personnel, as has been the case with Cisco, Google, AMD and other leading US firms. Their presence also promotes the cluster's image and facilitates external linkages, particularly if the multinational conducts business with local suppliers and begins working with local customers. Growth in the size of local firms and an expanding market base increases the administrative complexity they face and requires greater managerial expertise to deal with new challenges. The predominance of small- and medium-sized firms in many of the clusters means that much of this experience is in limited supply within the cluster, creating a potential barrier to further growth.

The Role of Anchor Organizations

Anchor organizations were pivotal in the emergence of clusters in seven of the eight case studies, and their absence in Cape Breton may be one reason why that cluster has shown little evidence of growth. While the specific anchor organizations differed from region to region, they played a similar role in focusing resources on exploiting the commercial potential of new knowledge and technology. The types of anchor organizations varied between large private firms (Ottawa, Toronto, Vancouver), a publicly regulated utility (New Brunswick), a joint venture formed by public utilities (Calgary) and public research institutions (Quebec, Waterloo). The crucial assets provided by the anchor firms were in-house capital and market linkages. Partnerships with external organizations were necessary to boost the resources of talent and knowledge. The presence of anchor organizations also brought other advantages to their respective regions. First, they provided stable employment for a large number of people and were often the employers of first choice for newcomers to the region. Linked to this was their pivotal role in workforce development and training, providing employees with a range of both technical and managerial experience, and spawning many of their region's future entrepreneurs. Anchor organizations acted as reservoirs of talent that were periodically released back into the marketplace.

As the clusters matured, the lead anchor firm's role often changed from a mechanism for organizing and focusing resources to releasing those resources into the cluster through the creation of spin-off firms, investments in startups, funding specialized training programmes, and through an increase in the mobility of its employees. With the increase in the number of firms in the cluster, the anchor firm itself often played a linking role between the cluster and external markets for the new SMEs in the cluster. To expand in relatively small local markets, the clusters had to build a strong international outlook in terms of resource flows and markets. Some of the SMEs were linked into international markets through partnerships or supply chain relations with anchor firms, perhaps working on a component of a larger technology that the anchor firm exported. All of

the case studies cited a strong export orientation and international linkages as critical for the current and future success of the cluster.

In those clusters where the anchor organization was not a leading firm, they still supported the growth of the cluster through spin-off firms. In regions with an established industrial base, such as Waterloo, the cluster benefited from strong links between industry and the local universities. A critical factor in the growth of the clusters in each instance was the ability to support and encourage early stage spin-off and startup firms. These firms play a central role in bringing new technologies to the market and helping the cluster to diversify. They allow cluster firms to experiment with new products without jeopardizing existing strengths and enable them to respond to changes in markets and emerging technologies. A region also needs to possess the skills and resources needed to grow these firms. A failure to support all stages of firm formation and growth limits the cluster's ability to grow and makes it vulnerable to mergers and acquisitions involving outside competitors.

Talent and Cluster Development

A consistent feature of the case studies is the centrality of skilled labour as the single most important local asset in attracting and holding firms in the region. The presence of a dynamic local labour market emerges from the attraction and retention of highly educated, potentially mobile workers who are drawn to the multiple employment opportunities created by the dense network of local firms. Places with "thick" labour markets are attractive because they provide skilled workers with the assurance of a range of career options. As Harrison *et al.* (2004, p. 1066) argue, ". . . it is organizations that attract talent to places. 'Magnet organizations' . . . play a crucial role in the development of technology clusters by attracting highly educated and skilled scientists and engineers into a region".

Although the presence of a thick labour market is often associated with the presence of post-secondary institutions in the cluster literature, it was more the exception than the rule in our case studies. The role of "magnet organizations" can be played by lead anchor firms such as NovAtel in Calgary or NBTel in New Brunswick, private sector research institutes, such as BNR in Ottawa, or public sector research organizations, such as the University of Waterloo or Université Laval. In most of our case studies, firms played the crucial role in developing skilled labour. The most important early source of talent in Ottawa was BNR, now part of Nortel Networks. The establishment of BNR in Ottawa in the late-1950s drew thousands of industrial engineers, researchers and managers into the region. This influx provided the critical mass of talent needed to exploit later developments in telecommunications and photonics. Vancouver and Calgary provide additional examples where large private firms created reservoirs of highly skilled labour. One interviewee in the Calgary case study referred to the training and network of contacts they had built up at "NovAtel University" (Langford *et al.*, 2003).

In most of our cases, the expansion of related research and teaching programmes at local universities and colleges lagged, rather than led the process of cluster formation. Two exceptions were at Laval in Quebec City where the cluster has been stimulated by the training of highly qualified personnel within local research institutes funded by senior levels of government and the University of Waterloo, which partnered with local industry to develop a successful cooperative education programme from the outset (Bramwell & Wolfe, 2008). Close collaboration between the universities and local industry in both

these cases fostered the transfer of novel research results into successful commercial products, as well as provided an earlier source of entrepreneurs for the local clusters. In the remaining cases, universities, colleges and other training centres became important sources of talent later in the cluster's life cycle, as the post-secondary institutions became adept at reading market signals regarding the direction of future demand for their graduates. As the number of firms within the cluster grew, there was an increase in the demand for labour, which encouraged firms to collaborate with local universities and colleges to coordinate training programmes (Wolfe, 2009). Industry representatives feel that specific programmes such as the coop programmes at Waterloo and others have been effective in moving students into industry settings besides providing an important source of tacit knowledge circulation within the cluster. The challenge of providing more advanced skills to meet the cluster's growing needs also appears to be one of the factors motivating the New Brunswick cluster to strengthen ties between universities and firms.

An abundance of labour brings with it several positive externalities. In the cases of Calgary, Ottawa, Toronto and Waterloo, the availability of highly skilled and specialized labour provides a strong attraction for outside firms. As the number of firms grows, there is also a greater opportunity for inter-firm mobility, which facilitates knowledge diffusion throughout the cluster. With growing employment opportunities there is also an increase in labour mobility within the cluster, which promotes knowledge flows between firms. This is seen in the reference to the Calgary "foot soldiers", reflecting the high degree of inter-firm labour mobility in the wireless cluster (Langford *et al.*, 2003).

The role of labour and talent also changes over the cluster lifecycle, as firms increase and diversify their technological capabilities in order to access new markets. As the cluster grows and firms expand their market reach, they require a wider range of skills, especially management and marketing skills, in order to improve their firm's capabilities. Increasing specialization, which results in anchor firms spinning off non-core activities into new firms, further stimulates the demand for specialized labour. Talent is present in different capacities and at different levels in each of the case studies reflecting the particular stage of development. Waterloo, Quebec, Toronto and Ottawa enjoyed an abundance of highly skilled and experienced labour, much of it engaged in R&D-related activities. Calgary and Vancouver also enjoy a highly skilled labour force across a number of different ICT segments. In New Brunswick and Cape Breton the skill level of the labour force was lower, but so was its cost, resulting in a relative comparative advantage that the regions tried to leverage to attract new firms. In the later stages of cluster development a key constraint on the ability of firms to grow is a lack of management and marketing skills. Because many of these skills are acquired through hands-on learning within the firm, the supply of managers relies heavily on in-house training carried out in large firms. The potential for more successful firms to be bought out by larger competitors—foreign and domestic—served as a double-edged sword in both releasing managerial talent into the cluster to facilitate the formation and growth of new firms, and in reducing the potential for managers to acquire higher level skills through local firms with a global reach. The smaller size of some of the clusters meant there were limited opportunities for managers to acquire the hands-on training and experience needed to effectively grow their firms and access export markets. The larger economic centres, with a more diverse mix of industries and broader economic base, are better able to provide the on-the-job management training to meet the needs of cluster firms.

Research Infrastructure and Knowledge Flows

The role of public organizations in cluster development has been the subject of considerable debate, starting with the case of Silicon Valley. Competing accounts of the origins and development of Silicon Valley differ significantly in the relative importance they attribute to the role played by Stanford University and UC Berkeley (Castells & Hall, 1994; Kenney & Patton, 2006; Lécuyer, 2005; Moore & Davis, 2004). While our case studies include only two instances where research universities were instrumental in the formation of the cluster, the presence of a strong research university contributes to the local antecedents in which the potential for cluster formation and development is greatly enhanced (Wolfe & Gertler, 2006). In Ottawa and Toronto the federal government contributed initially to the growth of the ICT cluster by investing substantially in public R&D facilities, whereas in Waterloo and Quebec City, increased federal and provincial support for post-secondary education in the 1950s and 1960s, and more direct funding for post-secondary research, especially through various Centres of Excellence programs in the 1980s, provided the stimulus for increasing technology transfer and new firm formation in the local cluster. Although we consider the University of Waterloo an anchor institution because of its key role in the creation of local talent and spin-off firms, local firms played a key role in mobilizing the resources needed to build the cluster. In Quebec City, the research institutions played a more direct role in incubating SMEs and providing infrastructure support for commercial activities. These cases illustrate the manner in which the public sector contributes to the development of the cluster by enhancing the local research infrastructure and knowledge assets or by expanding the local communications infrastructure.

Public research infrastructure contributes to cluster development in two additional respects—first, as a key source of new ideas for domestic companies, both in terms of spin-offs and knowledge transfer; and second, as a factor contributing to the reputation of the key clusters, thus helping to attract large foreign firms to invest in the province. Strong universities and research institutes act as attractors of inward investments by leading anchor firms interested in tapping into the knowledge base of the local community, or its local buzz, and as providers of the talent pool that firms in the cluster draw upon, rather than as direct initiators of cluster development. In this respect, universities also act as part of the network linking actors in the local cluster to the global pipelines that are essential to the knowledge flows in the cluster. Successful research universities also attract leading scientists, further reinforcing their linkages to external knowledge flows through the extensive network of contacts they bring to their new location. The case of Cisco (with respect to the Ottawa cluster) is widely cited as the most significant inward investment to the regional clusters, but Alcatel in Ottawa, and most recently Google in Waterloo, were also important. IBM, with one of its Centres for Advanced Studies located in its software laboratories in Markham, just north of Toronto, enjoys a strong working relationship with the University of Toronto and expanded its presence in the Ottawa cluster through the acquisition of two local software companies, effectively tripling the size of its Ottawa laboratories (Wolfe, 2002).

As clusters mature, their technological trajectories become more predictable. This enables cluster organizations and individual firms to better anticipate and therefore plan for future requirements for skills and knowledge. Past commercial successes and growing competitions also encourage firms to invest in incremental innovations to maintain their competitive advantage. With the growth of the cluster's relative economic

importance within a region, local research and training institutions have a greater incentive to collaborate on R&D and organize courses of study around cluster priorities. Cluster maturity provides new opportunities for partnerships between research and educational institutions and firms. This confluence of factors results in the gradual entrenchment of cluster supporting infrastructure in a region. This was evident in the organization of wireless and photonics programmes at local universities in Calgary and Ottawa and in the establishment of collaborative research institutes in Quebec and New Brunswick.

Thus a strong network of educational institutions is an important element in successful ICT clusters. The presence of a research university is a necessary, but not sufficient, condition for cluster development; not every region with a strong research university generates a dynamic ICT cluster. The role of the university in the cluster also changes over time. Universities are not only sources of research and innovation and the generators of human capital; as clusters mature, they also contribute to the incremental innovation that keeps firms competitive. Tangible links between the university and industry, in the form of both large-scale and more informal research collaborations, consulting by university faculty, and the movement of students back and forth to industry through coop placements, as well as permanent hiring upon graduation, all serve as conduits of knowledge that keep firms at the leading edge of innovation and keep universities relevant to local industry (Bramwell & Wolfe, 2008).

Global/Local Linkages and Knowledge Flows

A common strand in the cluster literature is the centrality of local linkages and knowledge flows in defining the geographical basis of a cluster. According to Porter (1998, p. 199), clusters consist of "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities". Key features of clusters are internal networking, linkages, and formal and informal interactions. This conception of the cluster incorporates key aspects of the Porter diamond by assuming that firms co-located in the cluster tend to be rivals in the same product markets or part of a locally based supply chain, and that close monitoring of competitors or tight buyer–supplier interaction are essential for the competitive dynamics of the cluster. The evidence from the ICT case studies suggests that these characteristics do not apply universally to all clusters—especially those in transformative technologies with global research networks, at an earlier stage of development, or in smaller, open national economies. The essential feature regarding linkages in the case of ICT clusters in Canada is their non-local dimension. Each of the cases reported global linkages to be as, if not more important, than local ones.

If Porter's conditions do not hold in all instances, this opens up the question of the relationship between the global and the local, and complicates the issue of whether local concentrations of firms in related sectors rely primarily on local sources of knowledge? A growing body of research, including the wider set of ISRN case studies (Gertler & Wolfe, 2006) recognizes that relatively few clusters are self-sufficient in terms of the knowledge base from which they draw. The knowledge flows that feed innovation in a cluster are often both local and global. Successful clusters are effective at building and managing a variety of channels for accessing relevant knowledge from around the globe (Bathelt *et al.*, 2004). However, the skills required to absorb knowledge from the local environment are substantially different from those needed to identify,

acquire and make use of knowledge produced elsewhere, and firms in the cluster must manage both tasks.

A key finding of the case studies is the early and continuing role of external linkages in the development of the ICT clusters. The amount of inter-firm collaboration in the form of local customer or supplier relationships is relatively low in most cases. For the majority of firms, the focus of their economic activity—key customers, sources of supply, competitors, important strategic partnerships and the resulting knowledge flows—occurs at the global level. The Toronto case study represents an important exception to this generalization with significant differences in the orientation of foreign and domestic firms. Foreign affiliates based in Toronto are primarily geared towards servicing the Canadian market as opposed to utilizing local knowledge resources to build a strong export base. These firms primarily adapt products for the Canadian market relying on research already conducted for their home markets. Some Canadian firms display the same inward orientation as the multinationals, but for the most part, the domestic firms, especially multiple location domestic firms, are more focused on external linkages, similar to our findings in the other case studies (Britton, 2003, 2004).

As firms expand into more competitive markets they need to expand their networks in order to identify and access the knowledge needed to continue innovating. If the knowledge base is global, as is the case with ICT, firms are required to monitor and assess international developments. This is done partly through local research collaborations and partly by partnering with external research organizations. While the existence of "knowledge pipelines" between local firms and external knowledge sources are critical to sustaining the regional competitive advantage, these pipelines often work in tandem with a strong local knowledge base. Most of the cases exhibit strong external linkages, some through the reach of multinational firms and others through research partnerships with local and non-local universities which typically maintain international research collaborations.

Some of the clusters display higher levels of internal networking (Calgary, Ottawa and Waterloo), information interactions and linkages, but these tend to occur through informal and interpersonal contacts. Linkages are found to exist between firms in related industries, such as photonics and telecom in Ottawa. Some firms in individual clusters rely upon a local supply base for certain inputs, but the vast majority draw components and knowledge inputs from a diverse array of geographical sources. The most important linkages, however, are to markets, particularly international markets, as many of the firms were geared to supply continental and international markets from their inception. A core theme that emerges from the case studies is the fluid nature of relationships between customers, suppliers and competitors in the cluster; explanations of ICT cluster dynamics that privilege local inter-firm relationships do not reflect the full complexity of their local and global relationships.

There are several explanations for this observation. First, this is a characteristic of small open economies and, in viewing the Canadian economy through a regional lens, each of these regions, in and of itself, is relatively small and open. Second, this is increasingly characteristic of ICT clusters in general. ICT is a highly export-orientated industry where geographically dispersed supply chains are the norm and locally embedded firms are connected to global networks of suppliers, customers and competitors. Recent work on Silicon Valley indicates that local production processes are part of a complex production chain tied into global production networks. The most dynamic multinational

corporations, and a large proportion of small- and medium-sized enterprises, have strong linkages to a variety of specialized clusters around the globe. Both types of firms use their presence in these local clusters to access specialized bodies of knowledge created by the local research institutions, or to tap into a specialized skill set or knowledge base developed by cluster-based firms. Rarely are the local knowledge bases of the clusters, or the production activities of cluster firms, completely self-contained. Rather, "what gets worked out in the clusters is exactly the codification schemes that are required to create and manage spatially dispersed but tightly integrated production systems" (Sturgeon, 2003, p. 200).

A strong export orientation is essential to the future viability of these clusters where growth depends on the ability of firms to identify and exploit international markets. Accessing international customers and suppliers and monitoring international competitors requires numerous skills and resources. A prominent export profile also contributes to the international reputation and branding that clusters such as Waterloo and Ottawa currently enjoy. Not only does this increase the reputation of regions, it helps attract new firms and labour (especially inward bound several multinational firms locating to the region as a result of the critical mass of companies and talent), thus contributing to the overall agglomeration effect.

Type of Knowledge: Research versus Development

Next to a thick labour market, the critical factor for cluster formation was access to a strong base of technical knowledge, but the role of that knowledge base varied from case to case and evolved over the lifecycle of the cluster. The early challenge was to transform this knowledge into commercial products and services, thus publicly funded research needed to be balanced with strong private sector development and design activities. In most cases, the lead anchor firms invested considerably in their own in-house R&D. Since much of the relevant knowledge base existed at the periphery of firms' current activities, knowledge sharing through partnerships and informal interactions with other local firms occurs often. The formation of NovAtel is a good example of two firms combining complementary knowledge—telephony in the case of Alberta Telephones and a recognition of the wireless needs of a geographically dispersed network of firms over difficult terrain in the case of Nova Corporation—to create a new source of expertise. Universities and research institutes subsequently supported this knowledge base with new and expanded research programmes.

Creating mutually beneficial linkages between public and private sector R&D requires complementary strengths. The Waterloo case represents one example of how a university contributed to cluster development with early spin-offs in the 1970s that paved the way for the next generation of startups in the 1980s and early 1990s. As the cluster matured, however, the pace of spin-offs declined, and firms reported that they relied on the university for a "first look" at leading edge research (Bramwell *et al.*, 2008). In other regions, such as New Brunswick and Ottawa, the universities were less important in the initial stages of cluster formation, but contributed subsequently with expanded research and teaching programmes. Deficits in one sector can also be compensated by strengths in the other, as shown in the Quebec case, where weak private R&D was offset by public research institutes increasing their development and design activities and taking a direct

role in commercialization. For regions in which both public and private sector R&D is weak, such as Cape Breton, innovation was more difficult to sustain.

Another consideration is the relative weight attached to research versus development in the individual cases. The studies reported a wide disparity in the R&D capabilities of large and small firms; larger ICT firms in our clusters typically have more robust in-house R&D units, which focus on the next generation product development in telecommunications, wireless, semiconductors or photonics in a constant effort to keep ahead of rapid technological developments in a global market. The medium and smaller firms typically have some in-house development group that brings a key technology to market or engages in small, limited one-off collaborative projects. Many of these firms in our cases confirmed that their emphasis is predominantly on solutions focused, incremental innovations, rather than research intensive, first generation innovations. Product and process improvements are intended to make the product "faster, smaller, cheaper", and involve activities such as the modification of existing software platforms, product updates and new releases, applying the core technology to different applications within the same factory, or making software web accessible (Bramwell *et al.*, 2008). In the Toronto case, Britton (2003) found that many of the firms were primarily focused on downstream or near to market product development. He concluded that this orientation provided an explanation for the relatively low R&D intensities of many of the firms, although all of the firms he surveyed were innovators.

The opposite was true of more scientifically oriented clusters, such as the Quebec City photonics cluster, where research activities are further removed from direct market application. In this case, however, R&D constitutes a necessary, but not sufficient, condition for cluster development. Regions that boast high levels of fundamental research struggle at times to capitalize on the commercial opportunities this presents. R&D strengths do not always translate directly into industrial and economic development. Moreover, as clusters mature they tend to focus their R&D activities on existing technological strengths. This facilitates research and educational partnerships, but may reduce the region's ability to develop new products and markets, leaving it vulnerable to being surpassed by more technologically innovative rivals. Existing firms need to continue seeking out commercialization opportunities and supporting the spinning-off of opportunities to new firms. Economic downturns, such as the post-2001 restructuring in the Ottawa telecom and photonics cluster, may also provide the opening for surplus knowledge assets from established firms to be recombined in novel fashion within the cluster through the formation of new, innovative firms.

The Role of Finance

High levels of R&D, and the accompanying potential for innovation and commercialization, often attract a ready supply of investment money and venture capital funding. The Ottawa case (and to a lesser extent Quebec City) experienced significant growth in the amount of venture capital funding flowing into the region in the later 1990s and early 2000s. Venture capital funding, however, can also bring certain disadvantages. In Ottawa, VC is described as a double-edged sword from which some firms have benefited significantly, while other SMEs cited lack of funding as a deterrent to growth. For those who did receive venture funding, there was increasing pressure to provide investors with a lucrative exit strategy, which often forced firms to engage in M&A activity, with

negative impacts on their ability to grow organically. While the Ottawa cluster has been home to Canada's most active venture capital community in ICT, the post-2001 downturn resulted in a significant reduction in this activity.

For the most part the firms in the clusters that comprise our case studies, with the possible exception of Cape Breton, claimed to have adequate early stage financing for new firms. Some of the clusters, such as Ottawa and Waterloo, developed effective networks of angel investors at an early stage, who used the experience they had gained to help launch successive rounds of startups. In Toronto, Ottawa and Waterloo some successful entrepreneurs went on to launch their own local venture funds. Many, however, experienced subsequent problems obtaining financing to support firm growth. This was the case in Calgary, Quebec and New Brunswick. In addition to private sources of financing, several federal and provincial government programmes were mentioned as important sources of firm financing—particularly the federal SR&ED tax incentive (and its provincial counterparts) and the grants available through the National Research Council's Industrial Research Assistance Program (IRAP). While most of the clusters relied primarily on private sources of finance, the Cape Breton case was the exception with its heavy reliance on government financing.

Where Canadian ICT firms continue to experience their most substantial financial difficulties is at later stages of development when they have grown sufficiently to become attractive takeover targets for foreign firms. As was noted almost two decades ago, Canadian capital markets have historically lacked the depth and investment experience to provide sufficiently large partners for the most successful domestic high-technology firms (Premier's Council, 1988). As a result, some of the most successful firms in our case studies were effectively lost to domestic control in the late-1990s and early 2000s—all three of the initial firms in the Vancouver wireless cluster, Delrina taken over by Symantec, Newbridge absorbed by Alcatel, Cognos acquired by IBM, JDS Fitel merged with Uniphase and after the downturn, consolidated most of its operations in California, and ATI, the leading domestic semiconductor firm in the Toronto cluster, taken over by AMD. This troubling pattern raises fundamental questions about the long-term potential for Canada's ICT clusters to achieve truly global status.

The Role of Civic Associations

The growth of clusters often leads to the formation of local civic associations that provide the member firms with a collective voice and an important means to agitate for supportive public policies. As Feldman *et al.* (2005) have noted, the recognition of the collective challenges facing a cluster leads the entrepreneurial founders of its firms to form the organizations needed to sustain their own activities and encourage new entrepreneurs to launch their own firms. These organizations also constitute an important mechanism for sharing hard-earned entrepreneurial and business skills and in the more effective associations, this mechanism is institutionalized through peer to peer knowledge sharing and mentoring relations. The establishment of these organizations raises the profile of the cluster in both the local, and more distant, economies and helps generate the kind of buzz that attracts new entrants and talent to the region. Civic organizations typically play a central role in the transition of the cluster to a more mature phase of development.

The emergence of dynamic local civic associations supports the growth of *civic* capital as a key contributor to the process of cluster development. Civic capital consists of

interpersonal networks and solidarity within a community based on a shared identity, expectations or goals and *tied to a specific region or locality*. Civic capital acknowledges the critical role of local leaders in intensifying and formalizing collaborative networks within and between communities. Many of our case studies witnessed the emergence of exactly this form of local civic association—WinBC in Vancouver, Calgary Technologies, Inc. in Calgary, Communitech in Waterloo, the York Technology Association and the Toronto Region Research Alliance in Toronto, the Ottawa Centre for Research and Innovation and the Quebec Optics and Photonics Association. In New Brunswick, the National Research Council attempted to fill the role of cluster mediator through initiatives linked to its research institute in Fredericton. These intermediary organizations often anchor the cluster, facilitating linkages among cluster firms and providing a portal for knowledge flows. This is clearly the case in the larger, more successful clusters among the cases; in some of the smaller ones, such as Quebec City, firms complained of an excessive degree of fragmentation, resulting from competing associations. Overall, the presence of local civic associations provided an important indicator of cluster dynamism and maturity (Wolfe & Nelles, 2009).

Conclusion and Policy Implications

Overall, the eight ICT cases covered in the ISRN's national study of industrial clusters in Canada followed a number of variable paths for cluster formation and growth. Each of the clusters evolved along different trajectories, with observable effects on their characteristics and potentials for success. In contrast to Michael Porter's oft-repeated assertion that governments cannot create clusters by fiat, the findings suggest that government plays a critical role in creating the antecedent conditions for cluster emergence. In some instances, such as Ottawa, Quebec and Waterloo, federal investment in public research institutes and post-secondary educational institutions provided the research infrastructure that contributed directly to the cluster's formation. In other instances, the government had a more indirect impact on the birth of a cluster, such as in the decision of the two key utilities to establish an anchor wireless firm in Calgary or the central role played by the publicly regulated telecom in New Brunswick. On balance, government investment in research infrastructure contributed to cluster development in several ways—through the attraction of inward investment to the region to tap into the specialized local knowledge base, through the direct spinning off of firms from its research, and through its contribution to a well trained and highly qualified labour force.

From a policy perspective, a key conclusion to be drawn from this observation is the importance of a sustained commitment to the development of a highly qualified workforce. Drawing on the experience of successful international software clusters, a prominent feature in countries such as Ireland was a sustained and long-term approach to educational policy (Sands, 2005). Commitment to building research infrastructure and workforce development is not just about meeting the current needs of industry, but also involves making investments in the research and knowledge capacity required for the ICT industries of the future. This entails continuous, long-term investment in education at all levels, but with particular emphasis on tertiary education, and an emphasis on the training of skilled researchers at the cutting edge of their respective fields of science, social science and engineering.

With respect to our second key question about the relative importance of local versus non-local factors for cluster development, the Canadian ICT clusters displayed openness to external markets and a strong export orientation. In virtually all of the cases, early and successful access to external markets was a critical factor in the success of the ICT firms that comprised the cluster. Both local and non-local dynamics operate in each of these clusters and they are by no means mutually exclusive. Local dynamics manifest themselves through knowledge flows and extra-firm networking mechanisms, referred to as a region's civic capital. Non-local factors involve market dynamics and the importance of global networks between suppliers, customers and competitors in the ICT industry. A firm's ability to build and maintain long-distant market linkages with suppliers and customers is based partially on its ability to access local business expertise and knowledge. Similarly, a firm's ability to identify and absorb knowledge from outside the region is based partially on its links with the local knowledge base. In answer to our third question, competitive success depends on the firms' ability to draw upon both local and external knowledge sources to develop and market successful products for international markets. This suggests that successful ICT clusters in Canada are both "regionally embedded" and effectively linked into global networks.

These findings suggest that the traditional dichotomy between public and private intervention fails to capture the complex dynamic between governments and firms needed to create and grow clusters. In the ICT case studies, a mixture of public and private firms, government and public research laboratories, post-secondary institutions and in-house firm research and training contributed to cluster development. The important question is not whether public or private initiatives drive cluster growth, but how effectively these initiatives complement each other and build on existing regional strengths (OECD, 2007). In adopting a cluster-based approach, government policy should identify the locational assets that exist in the cluster and devise initiatives to harness and mobilize those assets. At the later stages of cluster development, policies to sustain the entrepreneurial drive are also critical. These can include measures to support upgrading the innovative capacities of firms and promote the rapid diffusion of technologies, and networks to foster greater interaction among emerging SME's, as well as mentoring programmes for newly minted entrepreneurs. Often, local civic associations with support from local and regional government agencies can play this role. Cluster policies work most effectively where they succeed in aligning initiatives across senior levels of government with the current capabilities and future potential of local concentrations of firms.

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