HISTORY, CULTURE AND PATH DEPENDENCY: ORIGINS OF THE WATERLOO ICT CLUSTER

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INTRODUCTION

The search for effective cluster strategies remains an elusive goal, at best. Policy-makers at both the regional and local level are fascinated with the potential of cluster-based economic development to accelerate the growth of their local and regional economies. While previous policy studies have provided extensive lists of the key factors or prerequisites associated with the growth of strong and dynamic clusters, they are less successful at prescribing the most effective policies to support the formation of clusters or stimulate their early development. Indeed, some of the leading practitioners in the field maintain that clusters cannot be created by policy fiat and the best that governments can hope to do is support their growth once they have formed. However, closer examination of the origins and development of specific clusters suggests that the prospects for cluster policy are not quite so bleak. Central to this process are the relative importance of history and path dependence in the origins and development of clusters. Particularly significant is the nature of path dependencies created by small, initial events. The case of the information and communication technology (ICT) cluster in Waterloo, Ontario, is

instructive for developing a better appreciation of the implications of these factors for the process of cluster formation.

The industrial cluster in the Kitchener-Waterloo-Cambridge (Waterloo) region, located an hour west of Toronto, is one of the most dynamic sources of high-tech activity in the country. Geographically, Canada's Technology Triangle (as the region is also known) encompasses the four municipalities of Waterloo, Cambridge, Kitchener and Guelph. Although it is far from the largest concentration of information and communications companies in the country, the region boasts 468 companies involved in the production and facilitation of high technology. In addition, the region is home to strong firms and employment in automotive, advanced manufacturing, biotechnology, business and financial services, education, environmental science, food processing, furniture manufacturing, high tech, logistics and warehousing, R&D, and telecommunications (Canada's Technology Triangle, 2004). Currently automotive/metal manufacturing, education and business services sectors are the largest employers in the local economy (The Institute for Competitiveness and Prosperity, 2003). The economy is quite diverse within each sector. Unlike other concentrations of high-tech activity in Canada, the economy of the Waterloo region is not dominated by one particular sector, such as telecommunications or Internet-based firms. This diversity has enabled the regional economy to weather economic shocks - such as the post-2000 dot-com meltdown that devastated employment in other leading ICT clusters across the country.

Since its early days as a bustling manufacturing centre, the Waterloo region has been an important point on the Southern Ontario industrial landscape. Kitchener-Waterloo has been the home to major nationally and internationally successful corporations for more than a century, from Dominion Electrohome Ltd. to present day success, Research in Motion Inc. The region has

had a pioneering presence in some of the major technological advances in North America, including automobiles, radio, processed foods, financial services, biotechnology and computing. Today, this history of technological leadership continues in fields such as internet-enabled wireless communications, software, aerospace, engineering, e-commerce, robotics, and laser technology. The following discussion examines the origins of this vibrant regional economy and explores how a deeply rooted regional culture, historical patterns of trade and knowledge flows, and locally created institutions each contributed to the emergence of the region as a dynamic centre of high-tech activity. Along the way, it provides some valuable insights for policy-makers interested in emulating the region's cluster-based success.

CLUSTER FORMATION AND PATH DEPENDENCE

The concepts of path dependency and lock-in imply that a region's technological trajectory is historically determined by the factors that influence its economic development over time. The presence, or absence, of key institutional elements of the local innovation system may affect both its innovative capacity and its potential to serve as a site for cluster development. Similarly, the ability, or inability, of the local economy to develop the underlying conditions of trust and social capital that contribute to the presence of a learning economy may lock it into a specific innovation trajectory.

The concept of path dependence originated with the attempt by evolutionary economists to identify the factors which determine the selection mechanisms that influence technological choice and to analyze the technological trajectories that those mechanisms create. Since the

approach was formulated in the mid-1980s, it has been applied across a range of disciplines, including economic geography, innovation studies, political science, and sociology. The concept of path dependence was initially elaborated to explain how and why certain technologies emerge and prevail over alternate technologies in periods of rapid innovation. Paul David defines a path-dependent sequence of economic changes as one in which important influences upon the eventual outcome can be exerted by temporally remote events, including those dominated by chance elements, rather than systematic forces. He suggests that in a dynamic process, positive feedbacks are generated by strong technical complementarities on the supply side of markets, and/or the interdependence of customer preferences on the demand side. These may arise as well from learning effects and habituation associated with the sunk cost effects of new technologies - such as those involved in learning how use a new program (David 1997, 17) .

Evolutionary economists, historical sociologists and economic geographers have expanded on the original concept, suggesting that path-dependent analysis shares several common features. In the first place, it involves the study of causal processes that are sensitive to events that occur in the early stages of the causal sequence. Events that occur early in the sequence tend to exert a disproportionate influence over the long-term development path of the sequence. Secondly, these early events involve a high degree of chance or contingency that cannot be explained purely on the basis of the initial conditions since such conditions may lead to a wide range of possible outcomes. This makes it particularly difficult to forecast patterns of development based on the initial conditions. Finally, once the chance events have occurred, the path-dependent sequence exhibits a more deterministic pattern, involving a large degree of irreversibility. In economic systems, the degree of irreversibility is strongly reinforced by the effects of increasing returns to scale (Mahoney 2000; Davis 2004).

The complementary concepts of path dependence, increasing returns and lock-in have obvious relevance for understanding the historical paths taken by specific clusters in regional or local economies. Once a region establishes itself as an early success in a particular set of production activities, its chances for continued growth tend to be high. While this may be to some extent reducible to the success of dominant lead firms in the region, the aspect of this process of greater interest to cluster analysis has more to do with the collective processes and forces at work: local social and economic institutions and, yes, culture. In recent years, economists such as Paul Krugman and Brian Arthur have drawn upon a rich tradition of earlier ideas within economics and geography to fashion more formalized models of cluster development. Krugman, drawing upon an older tradition stemming from Alfred Marshall, specifies the types of supply side externalities that generate localized increasing returns. The first source is the large, deep pool of specialized labour created by the concentration of firms within similar industries in the same location. The second arises from the fact that a local concentration of firms in the same industry can also support a larger number of specialized local providers of intermediate inputs and services, and thus reduce the cost to firms. Finally, the co-location of similar firms in a region can generate positive technological externalities or spillovers that can flow more easily among the similar firms than over longer distances (although Krugman is more skeptical about this last factor). Overall, Krugman endeavours to show that the phenomenon of increasing returns is a key factor in the increasing sectoral specialization in particular regions over time (1991).

While Krugman's work focuses on the way in which scale economies and positive externalities can feed the process of industrial clustering, Brian Arthur's work specifies the way in which agglomeration externalities contribute to the concentration of firms in specific regions.

Arthur's interest in the question of industrial location grew out of his reading of Jane Jacob's classic work, *Cities and the Wealth of Nations*. He was "greatly taken by her haunting accounts of places and regions that had got 'passed by' historically in favour of other places and regions that had got ahead merely, it seemed, because they had got ahead" (Arthur 1994, xviii). His explanation for the basis of industry location patterns accounts for the degree of uncertainty introduced by agglomeration economies. The model accounts for both historical accidents and agglomeration dynamics.

> The process is path-dependent . . . in that a slightly different order-of-choice history early on could sway the outcome to a different location becoming dominant. An attractive location will likely be favoured by many firms early in the choice order, and therefore it has a larger probability of predominating. Attractiveness, interacting with historical accidents of choice-order, determines the outcome (Arthur 1994, 58-59).

Economic geographers have elaborated these insights by linking the analysis of path dependence to the underlying architectures of the respective regions. Maskell and Malmberg (1999) argue that the competitive success of firms depends on their ability to develop sustainable, distinctive capabilities. These capabilities are most likely to arise from non-ubiquitous and tacit forms of knowledge related to products, processes, and organizational routines within the individual firm. However, they will also arise from socially organized assets, such as localized, learning-based, inter-firm relationships that are not easily replicated by (groups of) firms elsewhere. Maskell and Malmberg argue further that a region's institutional

architecture accumulates and changes incrementally over time, and "thus represents the intricate contemporary interaction between elements of different ages … from the very old (religion, beliefs, values) to the recent/current (contemporary industry standards, current regulations, etc.)" (1999, p. 173). Because of these properties, this institutional endowment can become a key part of a region's non-replicable asset base and thereby reinforce durable local competitive advantages that are difficult for other regions to emulate. Gertler (2004) develops this idea more fully, showing how this regional institutional architecture consists of social structures that shape the attitudes, norms, expectations, conventions and - ultimately - the practices of individuals and firms in the region through informal and formal means of regulation. In other words, a regional economy's distinctive 'culture', and its path-dependent evolution are fundamentally rooted in a broader set of social institutions and relationships that extend and reinforce the competitive advantages afforded to the region by its initial concentration of firms in a given sector.

CULTURE, FIRM BEHAVIOUR AND INSTITUTIONS IN THE WATERLOO CLUSTER

The legacy of Waterloo's cultural roots, firm behaviour and core institutions are clearly visible in the contemporary contours of its ICT cluster. The industrial culture of the local economy bears a strong imprint of the German immigrants who populated the region in the nineteenth century. While the proportion of German population in Waterloo has gradually diminished over the years, the legacy of the cultural community that dominated the region during its formative periods is still evident. The very fact that the region has such expertise in high tech manufacturing and high value-added ICT industries owes a lot to an early regional specialization in engineering-intensive

industries. Furthermore, firm organization and behaviour seems to parallel the small and medium-sized enterprise (SME) model favoured by German - often family-run - firms.

The cluster also owes much of its continued success to local institutions with roots that date back to the early twentieth century - most notably, the local college which eventually spun off the University of Waterloo. The University of Waterloo is one of several colleges and universities in the region with strong ties to local industry, but it has exerted a singular impact on the regional economy. Decisions made about the shape and direction of its university programs at the critical formative stage had a decisive influence on the developmental trajectory of the regional economy. The following section traces the influence of these regional characteristics on the current economic landscape.

German Roots and Regional Culture: The Foundations of an Entrepreneurial and Globally-Oriented Cluster

The ethnic German composition of the community rooted in the immigration and settlement patterns of the mid- and late nineteenth century shaped the early industrial character of the region. Expertise in manufacturing produced a vibrant and diverse economic centre. The socio-cultural makeup of the community helped retain successful firms and engage the population in regional governance. Though the ethnic makeup of the Waterloo region is now much more diverse, some of the qualities associated with German culture continue to influence the local industrial landscape, firm structures and strategies, and patterns of local associational activity.

The earliest industries to emerge in the region included brewing/food and beverage manufacturing, textiles, wood processing, and rubber manufacturing. Although there was a mix of different industries between the two main towns of Kitchener and Waterloo, Kitchener (or Berlin, as it was called until 1916) specialized in rubber and woodworking, as well as their related industries (boot making and furniture building, etc.), while Waterloo was home to industries such as distilleries, breweries, textile mills and heavy agricultural manufacturing. These industries and towns grew through the late nineteenth century with the establishment of the Grand Trunk Railroad connection to Toronto, as well as the construction of the large hydro-electric plant at Niagara Falls that brought cheap power to the region.

Part of the early manufacturing success of Berlin and Waterloo is attributable to the ethnic roots of the region. Initially settled by Pennsylvania Mennonite farmers - quickly surpassed in number by German-speaking immigrants - these towns formed the urban center of ethnic-German settlement in Ontario in the nineteenth century. Early industrial success derived from the skill sets of these early inhabitants and socio-cultural factors that contributed to the 'stickiness' of the region. The ethnic German population brought an expertise in engineering and artisanal manufacturing - a product of the industrial character of German manufacturing of the period. Local inhabitants either formed their own companies or used their knowledge as labourers. A quick scan of the earliest firms in the region reveals a certain degree of technical expertise - Breithaupt tannery, Hoffman's planning mill, Vogelsang's button factory, Wegenast's saw and planing mill, Merner's iron foundary, Ziegler's cabinetmaking - virtually all of which depended upon the use of steam or water power, and later hydro-electricity.

What is remarkable is that these, and later companies, remained in the region despite compelling pressures to relocate to larger industrial centers. Of the 102 manufacturing businesses

established between 1850 and 1914, entrepreneurs of German origin founded approximately 73 percent. Though striking, this number is commensurate with their share of the total population (Walker 1987). What's more significant is that entrepreneurs, as well as workers, were attracted to Berlin and Waterloo by the German-language press, musical societies and other clubs, and distinctive denominational churches. These socio-cultural factors bound the local entrepreneurs to the community and the regional economy when, for purely business reasons, they might have moved away. This cultural attraction contributed to persistently high levels of local firm ownership and to considerably higher associational engagement within the community relative to Ontario towns of similar size.

The interwar years saw the growth of more complex engineering, metalworking, food and automotive-related industries on the foundation of the traditional manufacturing base. Several insurance companies established in the 1880s also grew and thrived during the 1920s. The growth of the insurance industry served as an important source of employment and a cushion against the boom and bust cycles of the manufacturing economy. The more modern sectors - insurance, automotive and metalworking industries - contributed to the relatively rapid recovery of the region from the economic decline of the Great Depression and continued to contribute to high growth as key sectors furnishing the manufactured requirements of World War II.

German regions are celebrated for their technical excellence in key engineering industries - the automotive sector, electronic, machine tool and printing machinery. The skill sets imported into the community by ethnic German individuals in this formative period helped propel the industrial basis of the region into more advanced manufacturing techniques from the mid-1800s to 1945. Now that Waterloo is home to a significant agglomeration of high tech firms, it is tempting to overlook this legacy of the German tradition of engineering expertise. One need only

look at employment statistics and regional skill sets to see that, while ICT is on the rise, it is the advanced manufacturing component of the high tech firms that dominates the regional economy. The influence of the German cultural tradition extends beyond the advanced manufacturing and engineering-intensive industries.

The Evolution of the University of Waterloo: Designing an Institution that Shaped an ICT Cluster

One of the key local institutions to emerge in the interwar period was Waterloo Lutheran College, established in Kitchener in 1924. Although the college did not contribute to high technology development in that era – it was an arts college associated with a seminary – its offspring, the Associate Faculties, played a key role as a precursor to the University of Waterloo. The college was created at the insistence of local business leaders and financially and academically supported by the community. . Several of the key actors in University of Waterloo story were also educated there. The Waterloo College project indicates the extent to which the two communities of Kitchener and Waterloo had developed a common regional and progressive identity based on local growth and its Lutheran origins a product of the local cultural community.

The College continued to grow and graduate students throughout the 1930s even as the Great Depression raged. It was the aftermath of WW II that inaugurated progress towards the foundation of a local university. The postwar experience brought home some important lessons for government and industry in Canada, and both local leaders and institutions in Kitchener-Waterloo played a key role in translating those lessons into practical measures. The University of

Waterloo, founded in 1957, emerged in response to the local and national demand for more sophisticated and technical educational institutions.

The industrial competition between leading powers in both the West and the Soviet block during the Cold War years of the 1940s and 1950s revealed serious gaps in Canada's post-secondary education system. In a world in which national survival was predicated on technological capabilities, Canada was found woefully lacking by industrialists and governments alike. In 1956 Canada's leading businessmen, scientists and educators convened the National Conference on Engineering, Scientific and Technical Manpower at St. Andrews-by-the-Sea, New Brunswick to discuss the extent of Canada's technical and engineering manpower shortage and to consider remedial action (McLaughlin 1997). They warned that "the problem of the universities has become an emergency of grave concern to the certain disadvantage of our progress as a nation, and can only be solved by energetic and immediate assistance and cooperation of all governments in Canada, of business and industry and of private benefactors" (Axelrod 1982, p. 24). This signalled a rapprochement in the previously distant relationship between industry and higher education - a new collaborative engagement in the crafting and support of the postsecondary educational system. Significantly, the members of the industrial community in Kitchener-Waterloo already enjoyed a close relationship with Waterloo Lutheran College through their membership on the Board of Governors and anticipated both the demands of the national economy for trained technical manpower and trends in the employment requirements of the local economy.

It was no coincidence that on August 27th, two weeks before the National Conference was set to commence, Ira Needles (president of BF Goodrich (Canada) and chairman on the Board of Governors for the newly created Associate Faculties of Waterloo Lutheran College) addressed

this specific issue in a speech to his local Rotary Club. Cognizant of the region's technical manpower shortage and growing industrial needs, and of the financial limitations and lack of experience of many educational institutions, Needles proposed a unique solution in the form of *The Waterloo Plan*. This plan called for a new type of education to be offered on a cooperative basis with industry. In sharing the burden of technical training with industry, the university would be able to support twice the number of students (when one class rotated out to co-op placements in industry another would take its place in the classroom), provide a greater depth of education - both theoretical and practical - and build a closer relationship with industry in order to anticipate employment needs, secure additional funding and ensure that classroom education remained on the cutting edge. This proposal became the basis for the University of Waterloo's highly successful cooperative education program, widely regarded as the best university co-op program in North American and a significant asset to the region.

The *Waterloo Plan* emerged from a confluence of national and local concerns. Although Waterloo College served the basic educational needs of the community in the areas of arts, humanities and theology, a movement had been underway for a short time – led by local industrialists – to expand the curriculum to include courses in science. Without a local source of engineers or technicians, local firms found themselves competing with the firms in major manufacturing (and educational) centres, such as Toronto, for talent. Local industrialists also realized the urgency of creating technological competencies and innovative capacities in the context of the Cold War. Many local industrialists came to feel that the future competitiveness of the region was closely tied to the establishment of better educational facilities. These concerns led to the creation of the Associate Faculties of Waterloo College (which shortly after became the University of Waterloo) - with a dominant emphasis on the scientific and technical

curriculum. The original plan incorporating the Associate Faculties assumed that it would remain affiliated with Waterloo Lutheran College, which would provide the liberal arts and social science components of the new university's curriculum. However, when the Associated Faculties acquired university status, the original college decided not to participate in the new institution. This serendipitous development resulted in the establishment of the new university with the overwhelming bulk of its faculty and course offerings in the sciences, math and engineering. Subsequently, Waterloo Lutheran College achieved independent university status as Wilfred Laurier University.

The University of Waterloo serves the regional economy in two important ways: by providing a pool of local talent and by transferring cutting-edge knowledge, either in the form of entrepreneurial spin off companies or through patenting, licensing, consulting or joint research projects. In its formative period the university was mainly concerned with the former aspect of its regional role and it set out to provide the best possible science, math and engineering curriculum possible. The cooperative education program rotates students to industry and back to the classroom on a regular basis, solidifying already tight relations with local industry. The reflexive relationship allows the curriculum to keep up with the ever-changing technological frontiers of industry, while strong industry support for the program has funded the acquisition of technology to enhance classroom learning. Waterloo became one of the first universities in Canada to enable students to actively explore and make use of innovations in the relatively new academic field of study - computing.

While local industry certainly had an interest in the development of the University of Waterloo as a source of talent it soon became clear that it would not produce the technologists – a professional degree – that local firms required. Almost from the beginning the university's

leadership decided to abandon the idea of trying to combine technological training with the study of engineering. Similarly, the new university also sought to apply the concept of mathematical modelling to its engineering curriculum and to introduce computing to its undergraduate curriculum. . The architects of this decision were Douglas Wright, the first dean of engineering, Ralph Stanton, chairman of the math department, and J. Wesley Graham, the director of the newly-established computing centre at the University of Waterloo.

The critical decision to focus the university curriculum on research in engineering, rather than simply providing a training program for technologists was the beginning of the university's high tech orientation. Wright understood that future developments in engineering would be very closely tied to the development of methods and modelling in mathematics (Wright, 2001). As such, he was anxious to work with Ralph Stanton, a mathematician who had come to Waterloo College from the University of Toronto to head up the math department. It was soon mandated that all engineering students take classes in finite mathematics and numerical analysis. Numerical analysis enabled engineers to solve problems and model scenarios that had previously been impossible using contemporary mathematical methods. Under Stanton and Wright's supervision the engineering program was one of the first to employ and teach these techniques – it was on the crest of what would be a new wave in engineering.

The next leap forward was initiated with the installation of the first computer. In 1959s Stanton recruited another key player in this story, Wes Graham, a former student of Stanton's from the University of Toronto who had gone on to work with IBM. With his background in computing Graham quickly got involved in a project to initiate a computer science program. The first computer arrived from IBM in 1960 – when there were just over 100 computers in business and university applications in all of Canada – and became the foundation of a computing centre

that was continuously upgraded by Graham, its director, though his extensive network of contacts. By 1967, the university had an IBM 360/75, the largest computer in Canada, which filled a room the size of a gymnasium and was designated as a backup for NASA's Apollo space missions. In Graham's view students should use computers as they do pen and paper and he was committed making sure that they could access and use the new machines. His vision for the computer science department revolved around these goals – access and usability – and therefore developed a focus on software rather than the traditional engineering and hardware development aspects of computing.

The first major ICT breakthrough at the university, and one that sealed its role as the key regional high tech institution, was an innovation in software – the WATFOR compiler. The only programming language available that allowed undergraduates to program computers was FORTRAN, but it lacked an efficient compiler that was needed for practical use by large numbers of students and faculty. Faced with this limitation, four undergraduate students created the Waterloo FORTRAN compiler to speed up programming computations. This technology, dubbed WATFOR, became the basis for one of the university's first spin-off companies and the first software company in Waterloo – WATCOM (1974), now parent company to several generations of subsequent spin-offs in ICT. The WATCOM spin off significantly established a business model with a relationship between the company and the university that allowed the company to retain ownership of its research and intellectual property which remains the basis for the university's current intellectual property policy. Furthermore, it provided an important example of the entrepreneurship which has become the basis for successive generations of university spin-off companies.

The establishment of the University of Waterloo in the late 1950s, was the seminal event that shaped of the subsequent development of the regional economy. The decisions made during its formative years laid the groundwork - in terms of determining regional expertise, capabilities and talent pool - for the emergence of an ICT cluster as the basis of the high tech economy. While the University of Waterloo is now one of many vibrant centres of knowledge creation it, more than any other university or college in the area, had the most profound effect on high tech industry in the region and is rightfully considered the institutional centre of this cluster. In our interviews with firms in the region the University of Waterloo invariably came up. Whether the firm engaged in collaborative research with individuals in the university, was a spin-off, used faculty or grad students as formal or informal consultants and problem solvers, funded a chair, employed co-op students or just acknowledged the various engineering, math and computer science programs as a source of talented graduates, the University was always mentioned. Regardless of levels of interaction, most actors in the region regard the University of Waterloo as the institutional core of the high tech economy.

The University of Waterloo has performed and continues to play three key roles in the development of the region's ICT cluster - as a major research university, it is at the forefront of knowledge creation in a variety of fields. It is also a key supply of talent that has contributed to the growth of a "thick" labour market in the local economy. Finally, through the process of knowledge creation and its strong support for entrepreneurship, the university has spun off several prominent firms in the area. While all three roles have had important effects on the shape of the cluster today, the one which attracts the most obvious attention to the local cluster is its role in spinning off high tech firms. University or public research organization (PRO) spin offs have long been a key goal of public policy makers and economic development officials. For one,

they indicate the presence of commercially viable research and are, therefore a mark of institutional success as well as a potentially positive return on public investment. The University of Waterloo is among the best performing universities in Canada in terms of the number of spin off companies it has produced. Since 1973, the University of Waterloo has spun off 59 individual high technology firms, 28 percent of the total number of high tech firms born in the cluster (Xu, 2003, 63). Some of the most notable spin-offs[1] include Waterloo Maple Inc (1988), Open Text (1989), Virtek Vision Corp. (1986), Dalsa (1980) and Northern Digital Inc (1981).

In addition to the University of Waterloo, the region is host to three other post-secondary educational institutions. The University of Guelph (1964), Wilfred Laurier University (1960), and Conestoga College (1967), specializing in agri-biotech, business, and technical trades respectively, have all been the source of additional spin-off firms. However, the University of Waterloo has undoubtedly been the most significant. One of the sources of the University's success in this respect derives from its intellectual property policy. Whereas many universities claim ownership of commercially viable intellectual property, at Waterloo the creators retain sole ownership of intellectual property . Interviewees claimed that this policy encouraging the individual (faculty or student) to commercialize their ideas. The combination of a permissive intellectual property policy and a strong regional entrepreneurial culture has contributed substantially to the high rate of new venture formation.

The nature of the commercialization process in the region, and in particular, the role of the University of Waterloo as a key institution in transferring new knowledge into the region has evolved considerably over the period. Whereas it played a more direct role as knowledge generator from the 1960 to 1980s, the declining number of spin-offs and the results of a social network analysis (Xu 2003) indicate that the university's primary contribution is no longer

primarily through the process of new firm formation. The findings from our interview questions on the impact of the university on local firm innovation strongly support this finding. Relatively fewer firms have spun out directly since the late 1980s and the post-2000 slump in the demand for high-tech products and services has resulted in a noticeable decrease in the availability of financing for start-ups and spin-offs. While the post-2000 downturn in the ICT sector has clearly had a negative impact on the regional economy, on the whole, it has much fared better than some of the other high-tech clusters examined in the ISRN's case studies, particularly the Ottawa-Hull region. Local observers have noted that while times in the region are tough, the wave of restructuring has not caused the magnitude of upheaval felt by the recent reversal in other tech communities such as Silicon Valley, Vancouver, and Ottawa (Crowley 2002).

Although the contribution made by the university to the growth of the cluster through spinning out university-based research in the form of new firms has declined in recent decades, this does not signify a decline in its relative importance for the local cluster. It continues to play a central role in training a significant proportion of the local labour force and in providing consulting advice and assistance in applied technology development to the local firms that employ its graduates. Local firms rely upon this advice as a critical source of knowledge inputs for ongoing product and process development (Bramwell, Nelles, and Wolfe 2004). Furthermore, University of Waterloo graduates make up a major proportion of the region's high tech labour force. Not only are graduates well trained within the university, they often come replete with practical experience gained through co-op placements in firms all over North America (but, for the most part, in firms in the region). Furthermore, many graduates are highly innovative and entrepreneurial - qualities emphasized in normal stream undergraduate courses and specifically

targeted through special limited enrolment programs and departments designed to provide a business background and resources to potential entrepreneurs.[2]

The fact that the University of Waterloo has developed such an expertise in training and graduating highly talented, innovative and entrepreneurial individuals in math, computer science and engineering is no coincidence. These areas of expertise developed over several decades and were the product of cultural context, certainly, but more specifically of purposive decisions taken by the innovative and visionary architects of the university and its early math and engineering departments. Thus the current character of the regional economy owes a lot to decisions made in the 1950s and 60s about the mandate and mission of the first regional university.

The evolving role played by the University of Waterloo in the formation and growth of the local ICT cluster provides strong confirmation of a more general observation arising from our national study of industrial clusters. The presence of leading research universities in a community is a necessarily, but not always sufficient factor to stimulate the formation of a dynamic and innovative cluster, or sustain the process of regional economic development. However, their presence can play a vital role in contributing to cluster development. As the Waterloo case illustrates, that role is not limited to simply acting as a source of scientific ideas for generating new technology to transfer to private firms, or as a source of new firm formation as research scientists spin findings out of their laboratories into start-ups. While successful research universities perform these functions, overall they play a more fundamental role as providers and attractors of talent to the local and regional economy and as a source of civic leadership for the local community (Wolfe 2005).

Ultimately, the Waterloo case study reinforces our finding that the most valuable contribution that universities make to this process is as providers of high skilled labour, or talent.

If knowledge is rapidly becoming the central factor of production in the emerging economy, the ability to absorb and use that knowledge, or to learn is the most essential skill or process. Learning processes are eminently person embodied in the form of talent. “Universities . . . are a crucial piece of the infrastructure of the knowledge economy, providing mechanisms for generating and harnessing talent” (Florida 1999, p. 72)

CURRENT SCALE OF THE WATERLOO ICT CLUSTER

Despite the relatively small size of the local community - the population of the Waterloo region was 438,515 in the 2001 census - the ICT cluster ranks among the top ten among census metropolitan areas (CMAs) in Canada and among the top thirty in North America on most indicators. The 2004 Waterloo Region Tech Directory lists a total of 468 firms active in the technology economy of the region (Silicon Valley North, 2004). While there are some extremely large players in the area - Research in Motion (RIM), COM DEV, Open Text, AGFA, and Descartes Systems being the best known examples - most of the high tech firms fall into the small and medium sized enterprise category. Almost 70 percent of high tech firms in the Waterloo region employ between 1 and 9 individuals, 20 percent have 10-49 employees, and around 6 percent fall into the 50-199 employee range. Only 3.6 percent of the firms in the region employ over 200 people.

High tech firms in the region fall into several different categories, such as wireless, systems and peripherals, applications, networking, security and data compression, among others. Though there may be several firms involved in a particular market segment or technology niche

within the region, they rarely compete directly with one another. One respondent noted: "There may be a lot of software firms here, but nobody does the same thing". This is a testament to the incredible diversity of high tech activity in the region. The competitive advantage of firms is the uniqueness of their products. Since these products are so highly differentiated, most firms in the region compete globally on the basis of this technical excellence, rather than on cost. This feature of local production culture distinguishes Waterloo from other major high tech clusters.

Most figures for high tech employment in the regional economy tend to be relatively low in that they fail to include advanced manufacturing, high tech financial services and biotechnology. The adjusted data from the ISRN's cluster study which relies on Industry Canada's definition of the ICT sector shows that ICT firms in the Waterloo region employed 11,160 people in 2002. The PricewaterhouseCoopers (PwC) TechMap notes that 45 percent of total employment growth is in high tech sectors, suggesting that ICT-intensive industry will continue to gain employment share relative to the more traditional manufacturing industries in the region (PwC 2001a). ISRN research also indicates that the region has an employment labour quotient (LQ)[3] of 1.35 in ICT related industries, marking a significant concentration of high tech labour relative to other CMAs in the country (Spencer and Vinodrai 2004).

Where the ICT sector makes its most significant contribution to the regional economy is in value-added. In a very conservative measure of ICT firms in the region, Canada's Technology Triangle (CTT) reported that in 2000 ICT companies generated over $8 billion in revenue. Furthermore, between 1993 and 1999 this sector's revenue increased 120 percent, assets increased by 163 percent and equity increased 420 percent, indicating strong actual and potential growth (CTT, 2003). While export figures don't specifically target ICT-intensive industry, the research also indicates that most of the ICT firms in the Waterloo cluster produce almost

exclusively for North American and global markets. The majority of measured exports from the region came from advanced manufacturing - including ICT-intensive - firms. In 2000, the region exported $8.9 billion worth of products, 55 percent of the region's GDP that year (CTT 2003). This suggests that, if more sectorally specific data sources were available, ICT-intensive industries would likely account for a substantial proportion of this activity. Export activity in Waterloo is so significant that measured by the dollar value of exports per employee it ranks third in comparison to all US metropolitan areas (CTT 2003).

The ISRN's national study of industrial cluster has developed a set of benchmark indicators to compare the individual cases being examined (Spencer and Vinodrai 2004). The Waterloo ICT cluster ranks consistently in the top ten in comparison to other Canadian ICT clusters, including those in the larger metropolitan areas. On measures of critical mass and growth Waterloo ranks 6th (out of 27) behind Ottawa-Hull, Calgary, Toronto, Montreal and Vancouver with an employment LQ of 1.35 and 13th with a 4.0 percent rate of growth in the number of establishments over the period from 1998-2002. In terms of average annual incomes of employees in ICT firms, Waterloo ranks at the median income of $50,000, in 9th place just ahead of Montreal.

The Waterloo cluster also performs well on measures of knowledge intensity. The region ranks 7th in terms of the percentage of the ICT labour force with a Bachelor of Arts (B.A.) degree or higher. Over 32 percent of the labour force in the region has a B.A. or higher degree. However, this measure may not accurately reflect the knowledge intensity of the labour force because it does not reflect those employees in the cluster with college degrees. Many ICT firms in the region employ graduates from the Conestoga College technology and technologist program. Though not university graduates, these individuals are arguably key knowledge

workers. If this group of highly skilled individuals is accounted for, over 57 percent of the regional labour force consists of highly skilled personnel based on educational attainment Another measure of knowledge intensity, which uses Richard Florida's creative class index (2002), finds that the Waterloo region's ICT workforce employs around 63.8 percent creative class workers. Further subdividing this measure reveals that 28 percent of the workforce is composed of those in science and technology occupations while 60 percent are considered knowledge workers Waterloo ranks 8th on this measure, just at the national average.

Other indicators of cluster performance are number of patents filed and dollar value of venture capital deals. In the period between 1998 and 2002 a total of 23 ICT patents were filed from the Waterloo region. On this measure Waterloo ranks 6th - behind Toronto, Montreal, Ottawa-Hull, Vancouver, and Oshawa but just ahead of Calgary. The relatively small number of ICT patents filed over this period has several potential explanations. It could indicate a maturing cluster - the initial rush of radical innovations that characterized the earlier days of the cluster may be in the process of settling down. Indeed, our qualitative work suggests that most firms in the region are engaged in incremental innovation, improvements on earlier products and processes (Bramwell, Nelles, and Wolfe 2004). Another possible explanation is that patents are being filed out of head offices outside of the region. A study commissioned by the Canadian Federal Department of Foreign Affairs and International Trade identified 196 foreign-owned firms in Waterloo in 2001 – the third highest absolute number of firms of any CMA in Canada (Matthew Fischer & Associates 2001). Many prominent firms from the US and Europe have research and development operations in the region and may file patent applications from their home office locations. The large presence of foreign-owned firms is generally attributed to the

attraction exercised by the University of Waterloo on firms interested in gaining access to both its research capabilities and the strong pool of highly skilled labour in the regional economy.

Venture capital numbers are also significant in the region, but pale in comparison with the larger numbers recorded by some of the other ICT clusters. With considerably under $1 billion in VC deals in ICT between 1998 and 2003 Waterloo ranks 5th in Canada. Again, this figure may not accurately reflect cluster performance. Many firms in the region are small to medium sized enterprises with low operating costs and financed by own source revenues. Most venture deals in the region have been with larger firms involved in the production of a physical product or component. Another factor could be the entrepreneurial nature of many firm founders. Some, but not all, prefer to maintain control over their operations rather than give equity to VCs. In any case, Waterloo performs relatively well on this indicator given its size and the level of development of the cluster.

The preceding analysis of these indicators illustrate that, while Waterloo is a dynamic, but primarily niche player in the global ICT industry, both the region and its ICT cluster have excellent potential for growth. The diversity of the regional economy and amongst ICT-intensive firms bodes well for its long-term stability and innovative potential. Although the cluster is small compared to those in Canada's larger urban centres, it is nevertheless, an instructive example of how a small Southern Ontario city that has developed a significant presence in the ICT industry.

FIRM STRATEGY AND COMMUNITY ASSOCIATION: A PATH DEPENDENT LEGACY

Many of the firms in the cluster share a common perspective on firm strategy, which, along with firm structure, carries the imprint of the German culture dating back to the nineteenth century. The prevalence of small and medium-sized enterprises in Waterloo, particularly founder-owned and operated ones, is further evidence of this legacy. The *Mittelstand*, or mid-size company, is the backbone of successful German regional economies (Cooke and Morgan, 1998).. Our empirical research clear indicates that some central characteristics of the *Mittelstand* - family/founder ownership, an emphasis on customized production, the role of system integrators, and some networking characteristics - do apply to the high tech SME landscape in the region. Beyond the explicitly German companies, many other high tech firms in the region have adopted similar practices of streamlined administrative structures, private ownership and founder operators. From one perspective this could result from the *type* of high tech production these firms are engaged in. After all, many produce in niche markets, require a relatively small number of highly skilled individuals for production, and little in the way of capital. Most have aspirations to grow revenues, but not the physical size of their companies. However, many high tech SME entrepreneurs are hostile to the idea of incorporating their firm into a larger concern through mergers and takeovers and value the creative control that the position of founder-operator affords.

Another feature of the Waterloo economy often associated with German regions is niche production and competition on the basis of technical excellence rather than cost. Production activities in the region are often decentralized and engage a dynamic group of highly skilled workers. Evidence for this can be found in the incremental and customer-driven innovation process where solutions-based research will involve different skill sets and workers depending

on the nature of the project. This prevalent characteristic of the Waterloo entrepreneurial culture is consistent with that found in the *Mittelstand.*

The legacy of Waterloo's ethnic German origins is also evident in a shared sense of community embeddedness. Cooke and Morgan (1998) identify certain types of relationships that characterize the associational strategies of *Mittelstand* firms. One aspect of this kind of networking is that it is often mediated through associations - business associations, tech transfer centres etc. Entrepreneurs in the region tend to be active in sustaining the quality of life and business in the region. Whether through philanthropy in support of the local cultural infrastructure or education or through involvement with various associational bodies, many local entrepreneurs are also community leaders. Originally it was the Germanic socio-cultural features of the region that fostered community engagement. Though only a few vestiges of this socio-cultural environment remain, the tradition of community engagement is still very strong relative to other communities of similar size. Like their forbearers, local entrepreneurial firms have chosen to remain in Waterloo rather than relocate to larger centres of high tech activity. Part of this has to do with the economic advantages that the region - particularly the pool of highly skilled labour - however, almost all the respondents mentioned a high quality of life and community as significant reasons for staying.

This type of associational activity is clearly evident in the growth of regional associations in the Waterloo high tech community focused on facilitating the region's economic competitiveness and sustainability. Canada's Technology Triangle (CTT), the Communitech Technology Association, the local Accelerate Network (now part of Communitech), and the Waterloo Reigon Prosperity Council all play important roles in supporting regional economic development. Recognizing both the cost of previous competitive relationships, and the

opportunity to collaborate for the economic benefit of the region, CTT was established in 1987 by the economic development officers of the municipalities of Waterloo, Kitchener, Guelph and Cambridge as a joint initiative to market the region. Generally, its purpose is to design marketing programs, facilitate networks and partnerships among business and educational institutions, design economic information systems, and to promote a climate of innovation, to complement and augment municipal development priorities and to build on its strength in regional information dissemination (CTT 1996).

In the first decade of its existence CTT made some progress towards raising awareness about the region and kept a regional economic database, but little headway in bringing the economic development agendas of the individual municipalities closer together or in achieving its other networking goals. One notable achievement was the creation of the CTT Accelerator Network (CTTAN), designed to help early stage firms become investment-ready by linking them with investors and providing ongoing support. Developed more in response to the availability of federal funding than a genuine regional consensus on economic development, the formation and subsequent governance of CTTAN (now run by Communitech as their Business Accelerator program), indicated widespread acknowledgement of the need for partnership and regional cooperation. The initial problems experienced by CTT are generally attributed to a lack of trust between municipal governments and the lack of confidence on the objectivity of the public sector in regional economic development matters (Roy 1998; Leibovitz 2003). Despite these initial problems, CTT has emerged as a strong force in the community, working to raise the profile of the region in the high-tech world through its own initiatives and in partnership with Communitech.

Communitech, formed in the late 1990s to lobby the government in the interests of high-technology business, has been an important addition to the institutional infrastructure of the cluster in the Waterloo region. It was created as an initiative of a group of high-tech entrepreneurs with the specific purpose of establishing cutting edge infrastructure to support regional high-tech prosperity, expansion and global competitiveness. Communitech grew out of the Atlas Group, a group of 12 CEO's who met informally to facilitate the exchange ideas and improve networking relationships between them. Members of the group recalled that meetings helped to raise the amount of "talk" in the tech sector and the sense of belonging to a high-tech community. An often-cited benefit of Communitech membership is precisely this sort of access to a pool of shared experiences and support through seminars, Peer2Peer sessions, networking events, and conferences. The association has fulfilled this role and improved the ability of firms in the region to grow globally. More recently, CTT, Communitech, the Greater Kitchener Waterloo Chamber of Commerce and the Cambridge Chamber of Commerce have come together as the Prosperity Council of Waterloo region to collectively create an environment that supports opportunities for prosperity in Waterloo region. Together they represent more than 3000 businesses in Waterloo region. Prosperity, for the purposes of the Council, involves initiatives and policies that support wealth creation, supporting the objectives of enhancing the standard of living and overall quality of life in the region.

CONCLUSION

The case of Waterloo Region's ICT cluster provides clear support for the argument made about the long-term impact of expanding research infrastructure on the development of local clusters. In the Waterloo case, the mobilization by local business leaders to secure a charter for a new

university, financed with federal and provincial funding, and their foresightedness in structuring a curriculum around math, sciences and engineering and creating a pioneering program of co-operative education, all laid the groundwork for the future emergence of a dynamic and growing information technology cluster. However, one should not overlook the supportive role played by the senior levels of government - the federal and provincial governments - whose expansion of support for the post-secondary education system in the 1960s made possible the establishment of a new university. It was the specific pattern of interaction between dynamic, visionary leaders at the community level with the increase in federal and provincial funding that created the local antecedents essential for the emergence of the information technology cluster (Wolfe and Gertler, forthcoming).

The lesson here is that the path dependencies for cluster creation are highly variable, and that the chance events which provide the trigger for cluster formation can come from many sources. The Waterloo case strongly reinforces the point made by leading economic geographers concerning the intersection of historical context and chance occurrence in launching a regional or local economy along a certain trajectory of development. Visionary leadership by members of the local business community was an essential factor in launching the regional economy onto its high tech trajectory. But that leadership itself was a product of the past history of manufacturing competence, local entrepreneurship and community engagement that reflected the historical roots of the local economy and its largely immigrant population. Public sector involvement can influence cluster trajectories in a variety of ways, unpredictable as those may be. Whether intentional or inadvertent, one of the most effective public policies for seeding cluster development is a sound investment in building the research and skilled labour base in a region. The establishment of a strong local talent pool of highly skilled and knowledgeable workers both

feeds the growth of the local firms in the cluster as increasing returns begin to take hold, and attract outside firms to invest in the cluster to gain access to the 'local buzz'.

However, the presence of a strong local research infrastructure and a 'thick' local labour market may not be sufficient on their own to spur the formation of a local cluster. Many clusters enjoy the knowledge assets and research infrastructure that are necessary for the development of an innovation-based development strategy, but they differ dramatically in their capacity to mobilize these assets in the pursuit of such a strategy. Similarly, the ability, or inability, of the local or regional economy to develop the underlying conditions of trust and social capital that contribute to the presence of a learning economy may create a condition of lock-in to a specific innovation trajectory. The Waterloo cluster owes its current success to the effective intersection of a strong sense of civic engagement with the rich knowledge resources afforded by its strong research infrastructure and talented local labour market.

NOTES

[1] There is some confusion in the literature about firm formation in the region about what constitutes a university spin-off. Many accounts include firms founded by university alumni or students in this category regardless of the source of the core technology or intellectual property. In the interest of precision we employ a more rigorous definition. A university spin-off company is "a commercial entity that derives a significant portion of its commercial activities from the application or use of a technology and/or know-how *developed by or during a university funded research program*. The new enterprise is created either (1) to license a University invention, (2) to fund research at the University in order to further develop a technology/invention that will be

licensed by the company, or (3) to provide a service using University-derived expertise" (University of Alberta Research Services Office, 2003). Accordingly, Research in Motion, a firm often credited as a University of Waterloo spin-off is counted in this paper as an independent start up. It was founded while both principles were still students at the university but as a consulting firm unrelated to their areas of study. Because no technology or IP was transferred at the time of its founding, RIM is not considered as a university spin-off, irrespective of any research contacts it currently has with the institution.

[2] The Enterprise Co-op Program enables students to start their own venture in lieu of doing a co-op placement with an established firm. The program focuses on creating a local network of contacts and mentors to support the venture though the university does not directly support the actual venture. The Masters in Business, Entrepreneurship and Technology (MBET) is a graduate degree program that attracts potential entrepreneurs from around the world. Its mission is to provide business skills critical to identifying and exploiting commercial opportunities with emphasis on technological, innovative and entrepreneurial energies that are the foundation of the University of Waterloo's reputation. Innovate Inc. is a department within the university that provides resources and counselling to faculty and student entrepreneurs and aims to facilitate the commercialisation of knowledge created within the institution.

[3] The location quotient calculates the proportion of the labour force in the local economy employed in a given sector, such as ICT, relative to employment levels in other CMA's across the country.

REFERENCES

Arthur, W. Brian. 1994. *Increasing Returns and Path Dependence in the Economy*. Forward by Kenneth J. Arrow. Ann Arbor: The University of Michigan Press.

Axelrod, Paul. 1982. *Scholars and Dollars: Politics, Economics and the Universities of Ontario, 1945-1980*. Toronto: University of Toronto Press.

Baine, Janet. 2001. "Guelph out of the Triangle," *Silicon Valley North GTA* 6(5) Feb: 8.

---------. 2000. "Canada's Technology Triangle shrinks and takes a new shape," *Silicon Valley North* 4(5) July: 36.

Bank of Montreal. 2000. "Canada's Technology Triangle: The Future Looks Bright," BMO Economics. Autumn.

Bathelt, Harald. 1991. *Schlüsseltechnologie Industrien: Standortverhaltern und Einfluβ auf den regionalen Struckturwandel in den USA und in Kanada*. Berlin: Springer-Verlag.

Bathelt, Harald and Alfred Hecht. 1990. "Key technology industries in the Waterloo region: Canada's technology triangle (CTT)," *Canadian Geographer* 34 (3): 225-234.

Bathelt Harald, Anders Malmberg and Peter Maskell. 2004. “Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation,” *Progress in Human Geography* 28,1, pp. 31-56.

Bloomsfield, Elizabeth. 1987. “Building Industrial Communities: Berlin and Waterloo to 1915,” in Walker (ed.) *Manufacturing in Kitchener-Waterloo: A Long Term Perspective*. Waterloo: University of Waterloo.

---------. 1987. “The maturing industrial economy: Kitchener-Waterloo, 1915-1945,” in Walker (ed.) *Manufacturing in Kitchener-Waterloo: A Long Term Perspective*. Waterloo: University of Waterloo.

Bradford, Neil. 2003. “Cities and Communities that Work: Profiles of Innovation,” CPRN paper F-71 August.

Bramwell, Allison, Jen Nelles and David A. Wolfe. 2004. “Knowledge, Innovation and Regional Culture in Waterloo’s ICT Cluster.” Paper presented to the Annual Meeting of the Innovation Systems Research Network, Vancouver, BC, May 12-15.

Canada’s Technology Triangle. 1996.

Canada’s Technology Triangle. 2004. *Community and Statistical Profile*. Waterloo.

Crowley, Kevin. 2002. “Weathering the storm; Waterloo Region's Tech Sector thrives despite industry's global downturn,” *Waterloo Record*. October 24.

Cooke, Philip and Kevin Morgan. 1998. *The Associational Economy: Firms, Regions and Innovation*. Oxford: Oxford University Press.

David, Paul. 1997. Path Dependence and the Quest for Historical Economics: One More Chorus of the Ballad of QWERTY. Discussion Papers in Economic and Social History, No. 20. Oxford: University of Oxford.

Davis, Charles. 2004. “Path Creation and Destruction in Industries, Regions and Firms: Strengths and Limitations of the Concept of Path Dependence in Innovation Studies.” Paper presented to the Annual Meeting of the Innovation Systems Research Network, Vancouver, May 12-15.

Eastwood, Donald. 1987. “The University of Waterloo, High Technology and New Firm Creation,” in Walker (ed.) *Manufacturing in Kitchener-Waterloo: A Long Term Perspective*. Waterloo: University of Waterloo.

English, John and Kenneth McLaughlin. 1996. *Kitchener: An Illustrated History*. Toronto: Robin Brass.

Florida, Richard. 1999. "The Role of the University: Leveraging Talent, Not Technology." *Issues in Science and Technology,* Summer.

Florida, Richard. 2002. *The Rise of the Creative Class: And How Its Transforming Work, Leisure, Community and Community and Everyday Life*. New York: Basis Books.

Gertler, Meric S. 2004. *Manufacturing Culture: The Institutional Geography of Industrial Practice*. Oxford: Oxford University Press.

Institute for Competitiveness and Prosperity. 2003. "Presentation to the Prosperity Forum, Waterloo Region." February 4.

Knafelc, Paul. 2003. "A comparison between the socio-economic performance of Canada's Technology Triangle – the Waterloo Region and Ontario's Census Metropolitan Areas," Community Benchmarks prepared for the Prosperity Forum. February 4.

Krugman, Paul. 1991. *Geography and Trade*. Cambridge, Mass.: MIT Press.

Leibovitz, Joe. 2003. "Institutional Barriers to Associative City-region Governance: The Politics of Institution-building and Economic Governance in 'Canada's Technology Triangle,'" *Urban Studies*. 40:13 (December): 2613-2642.

Levesque, Peter. 1993. “Canada’s Technology Triangle: Designing a Role for Regional Government in Emerging Advanced Technology Based Economy” [MA Dissertation]

Mahoney, James. 2000. “Path Dependence in Historical Sociology.” *Theory and Society* 29: 507-48.

Maskell, Peter and Anders Malmberg. 1999. “Localized learning and industrial competitiveness”, *Cambridge Journal of Economics* 23: 167-86.

McLaughlin, Kenneth. 1997. Waterloo*: The Unconventional Founding of an Unconventional University*. Waterloo: University of Waterloo Press.

McReady, Doug. 1985. “Economic Impact of Wilfred Laurier University and University of Waterloo on the Kitchener-Waterloo Region”, Occasional Papers in Business and Economics Waterloo: Wilfred Laurier University.

PwC. 2001a. “Canada’s Technology Triangle Techmap 2001” Waterloo.

PwC. 2001b. “University of Waterloo: Regional Economic Benefits Study.”

PwC. 2001c. “Regional Economic Benefits Survey.” August.

Roy, Jeffrey. 2000. “Government and Governance in high-tech localities: Ottawa-Carleton and Canada’s Technology Triangle” [PhD dissertation] Ottawa: National Library of Canada.

---------. 1998. “Canada’s Technology Triangle” in John de la Mothe and Gilles Paquet, eds, *Local and Regional Systems of Innovation.* Boston: Kluwer.

Spencer, Greg and Tara Vinodrai. 2004. “Analytical Measures to Assess and Evaluate Clusters.” Presentation to the ONRIS-MEDT Fall Workshop, Toronto, Oct. 21.

Stanton, Raymond. 1997. *Visionary Thinking: The Story of Canada’s Electrohome*. Kitchener: Canadian Corporate Histories.

Walker, David. 1987. *Manufacturing in Kitchener-Waterloo: A Long Term Perspective*. Waterloo: University of Waterloo.

Wolfe, David A. 2005. “The Role of Higher Education in Regional Innovation and Cluster Development,” in *Creating Knowledge, Strengthening Nations*, Eds Glen Jones, Patricia McCarney and Michael Skolnick (Toronto: University of Toronto Press).

Wolfe, David A. and Meric S. Gertler. Forthcoming. “Local Antecedents and Trigger Events: Policy Implications of Path Dependency for Cluster Development.” In Cluster Genesis: The Emergence of Technology Clusters, Eds Pontus Braunerhjelm and Maryann Feldman.

Xu, Stephen Xingang (2003) “Knowledge Transfer, Interfirm Networking and Collective Learning in High Technology Cluster Evolution: A Network Analysis of Canada’s Technology Triangle” [Master of Applied Science (Management Science) dissertation] University of Waterloo.

Zeidenberg, Jason. 1995. “Lost in the technology triangle,” *This Magazine* 28(5): 33-7.