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The Evolution of Knowledge Clusters

Progress and Policy

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The economic downturn post-2000 badly undermined the rapid growth of knowledge-based and technology-led sectors. This article reflects on post- and pre-2000 development from the perspective of the evolution of regional clusters of knowledge-based activity. Four case studies of knowledge clusters are presented—Silicon Valley (United States), Cambridge (United Kingdom), Ottawa (Canada), and Helsinki (Finland)—as a means of understanding how the modus operandi of such clusters is evolving. The author finds that knowledge cluster development is shifting from one of internal reliance to models based on wider connectivity and consolidation. It is these new patterns of connected clusters and broadened knowledge networks that both firms and policy makers are increasingly attempting to foster. A framework outlining the key stages of evolution through which knowledge clusters advance is proposed. The author concludes that cluster policies must be increasingly attuned to positioning within a global network environment.

Keywords: *clusters; knowledge economy; regional evolution; policy; high technology*

As economic and technological change occurs with ever-increasing speed, corporate managers and public policy makers alike are grappling with the question of how to achieve sustainable growth and competitiveness within the evolving and complex web of blurred socioeconomic business activity. The emergence of the global knowledge economy is creating innovative systems and models of work, business interaction, and production that are only just beginning to be understood. In recent years, those seeking to find such an understanding have had many of their beliefs and analyses shaken as a result of the economic downturn post-2000. This badly undermined the rapid growth of the knowledge-based and technology-led sectors in the middle and late 1990s. Now that the dust is finally settling on this bubble-bursting episode, it is important to reflect on developments and, in particular, the ongoing evolution of clusters of knowledge-based activity.

The concept of clusters, as developed by Michael Porter (1998), has rapidly become the focus of economic competitiveness theory and policy. The underlying tenet of this theory is that national competitiveness is determined by the strength of key concentrations of specific industries within a nation. Porter's definition of a cluster is a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities. These clusters possess a socioeconomic business culture linking certain fundamental conditions that are the drivers of economic growth within nations. Clusters are considered as offering a means for creating higher value-added by tapping into and distributing the potential of local strengths as a whole rather than as a series of fragmented companies (Roelandt & den Hertog, 1998).[1] In particular, clusters can positively influence economic growth in three core ways: by increasing the productivity of companies based in an area; by driving the direction and pace of innovation, underpinning future productivity growth; and by stimulating the formation of new businesses, expanding and strengthening the cluster itself.

Although the focus on knowledge-based economics is indicative of the source of modern economic growth, clusters are often the physical manifestations of the source's centers. The effect of the knowledge revolution is such that knowledge workers are the core agents of the knowledge economy (Audretsch, 1998). With the emergence of a cluster culture, these knowledge workers possess the ability to transfer and exchange knowledge through what Romer (1990) describes as effective mechanisms for supporting collective interests and producing new ideas. Innovation is at the heart of competitive advantage attainment, and it is

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changing the ecogeographic landscape as knowledge clusters become the key drivers of the prosperity of nations. These clusters are focused on the intellectual and knowledge capital residing within and exchanged among individuals, firms, and other knowledge-creating institutions such as universities. The dynamism of knowledge clusters is such that there is an ever-changing balance in the relative importance of the conditions leading from the genesis of a cluster to its growth and sustainability.[2] For instance, clusters are often seedbeds for infant industries, whereby a new product's frameworks have not yet matured into a specific identifiable technological trajectory. Clusters facilitate the requirement for technological development before a product's full commercialization, which often involves high levels of openness for new ideas and combinations of firms and individuals (Fleming & Marx, 2006)

As Castells and Hall (1994) illustrate, the development of knowledge clusters involves the close integration of the "usual" factors of production—capital, labor, and raw material—brought together by some form of institutional entrepreneur and constituted by a particular form of organization. The raw materials consist of new knowledge percolated through a highly networked business culture. A network culture based on strong ties is generally seen to be consistent with the transfer of complex knowledge, requiring the type of face-to-face interaction facilitated by the geographic proximity of firms and other actors (Bathelt, Malmberg, & Maskell, 2004; Sorenson, Rivkin, & Fleming, 2006). The existence of established spatially proximate knowledge networks is commonly considered to be one of the key reasons why a number of the most successful localities and regions throughout the world have become or remained more industrially competitive than those not adopting a networked approach (Lawson & Lorenz, 1999; Saxenian, 1994). Many firms, however, do not acquire their knowledge from within geographically proximate areas, particularly those firms based on innovation-driven growth, where knowledge is primarily sourced internationally (Davenport, 2005). If applicable knowledge is available locally, firms and other institutions will attempt to source and acquire it; if not, they will look elsewhere. Also, although firms with a low capacity to absorb knowledge—absorptive capacity—tend to network locally, those with higher absorptive capacity may be more connected to global networks (Cohen & Levinthal, 1990; Drejer & Lund Vinding, 2007). This is perhaps to be expected and illustrates the importance of internal knowledge absorption capacity on external knowledge network development. There is growing evidence that nonspatially proximate actors are often equally, if not better, able to transfer complex knowledge, which is often superior to that available locally, resulting in improved innovation performance across such spatial boundaries, provided a high-performing network structure is in place (Dunning, 2000; Lissoni, 2001; McEvily & Zaheer, 1999). This highlights an important association between the external knowledge requirements of firms and future knowledge cluster development—in particular, policies seeking to sustain existing or nurture new clusters.

Silicon Valley is by far the world's largest and best-known example of a functioning cluster based on knowledge-intensive and networked economic activity. Other examples from North America of knowledge cluster locations include Boston (the Route 128 cluster), Seattle, Los Angeles (Hollywood), San Diego, Austin, and Ottawa in Canada. Examples from Europe include Helsinki in Finland, Munich and Stuttgart in Germany, Paris and Rhone-Alpes in France, Stockholm in Sweden, and Oxford and Cambridge in the United Kingdom. In Asia, knowledge clusters can be found in Tokyo, along with newer but rapidly growing knowledge clusters in Beijing, Shanghai, and Bangalore. These clusters consist of high densities of firms generally engaged in one or more of information technology (IT), biotechnology, medical instrumentation, automotive, or other high-technology industrial manufacturing or knowledge-intensive service activities such as information and communication technology (ICT) applications and other high-end professional business services.

This article presents case studies of four knowledge clusters as a means of understanding how the modus operandi of such clusters is evolving. I find that knowledge cluster development is shifting from a model of internal reliance to a model based on wider connectivity and consolidation. The study finds that knowledge is increasingly flowing across clusters, resulting in heightened global knowledge connectivity. It is these new patterns of connected clusters and broadened knowledge networks that both the firms and policy makers are increasingly attempting to foster, although the push from either the corporate or the government sector varies across clusters. The article develops a framework outlining the key stages of evolution through which knowledge clusters advance. The case study clusters are Silicon Valley (United States), Cambridge (United Kingdom), Ottawa (Canada), and Helsinki (Finland). These clusters are chosen to represent a broad cross-section of knowledge clusters based on two key parameters. First, they represent clusters with differing levels of maturity. Both Silicon Valley and Cambridge have been centers of knowledge-based activity since the 1950s and 1960s, whereas in Ottawa and Helsinki such growth is relatively recent, mainly dating to the 1990s. Second, the type of

Figure 1
Attributes of Case Study Knowledge Clusters

Level of Cluster Maturity	Knowledge Diversification	Knowledge Specialization
Mature	**Silicon Valley** 13,000 firms 340,000 employees Key Sectors—Primary: ICT; Secondary: Biomedical; creative and innovation services	**Cambridge (UK)** 900 firms 30,000 employees Key Sectors—Primary: ICT; Secondary: Life sciences
Early-Stage	**Ottawa** 1,000 firms 50,000 employees Key Sectors—Primary: ICT; Secondary: Life sciences; photonics; professional services	**Helsinki** 1,100 firms 66,000 employees Key sectors—Primary: ICT; Secondary: Life sciences

Level of Knowledge Specialization

Note: ICT = information and communication technology.

knowledge at the core of each cluster differs. Although all the case study clusters are principally based on ICT, with secondary activities related to life sciences and biotechnology, Silicon Valley and Ottawa are more diversified than are Cambridge and Helsinki. In particular, Silicon Valley and Ottawa have higher concentrations of service-based knowledge-intensive activities. In the case of Cambridge, growth in this area has been limited, possibly because of the relative proximity of the cluster to London, whereas in Helsinki much of the development of the cluster has been in the sphere of mobile telecommunications. Figure 1 provides a summary of the key attributes of the clusters. We begin by examining the world's archetypal knowledge cluster—Silicon Valley.

Silicon Valley

The origin and subsequent development of Silicon Valley are now well-rehearsed narratives, most often traced to the founding in 1908 of Federal Telegraph in the region and its development of wireless technology, coupled with the importance of defense spending and the role of Stanford University (Adams, 2005; Kenney, 2000). These resources and the relationships they fostered provided the launching pad for a host of pathbreaking entrepreneurs who located their activities in the region (Kaplan, 1999). At the time, these entrepreneurs were responsible for establishing some of the largest Silicon Valley firms such as Eitel-McCullough (Eimac), Litton Industries, Varian Associates, Fairchild Semiconductor, and Intel, which came to dominate markets for advanced tubes and semiconductors, while also stimulating a whole host of related activity in the region (Lécuyer, 2005). Following the semiconductor crisis of the 1980s, Silicon Valley witnessed a rapid resurgence and by the end of the 1990s was not only the economic model everyone was seeking to emulate but was also almost single-handedly seen as the driver of U.S. and even global economic growth.

In a 1999 article in *Harvard Business Review,* Gary Hamel highlighted the 41 initial public offerings (IPOs) that had taken place in Silicon Valley the previous year, which had a combined market capitalization of $27 billion, to present a eulogy of the Silicon Valley model, arguing that "never has so much wealth been created in so little time by so few people" (p. 72). However, it was the inflated stock prices achieved by these IPOs, primarily on the NASDAQ—the public stock market for technology companies in the United States—that led to another wave of disruption to the Silicon Valley model, which came with the bursting of the so-called economic bubble in 2000. The impact of the adjustment in stock prices in 2000 contributed to a loss of 25,000 Silicon Valley jobs in 2001 (almost 2% of total employment) and more than 200,000 jobs by 2006, and although a significant proportion of these jobs was replaced, the total workforce dropped by approximately 120,000 people (Joint Venture, 2007).

Ironically, although Hamel's (1999) article now seems shortsighted at best, his overall analysis of Silicon Valley's core business model is fundamentally correct. This model is based on attracting resources—principally human and financial capital—willing to take the risk of nurturing the innovation produced within the cluster. In this instance, the initial value placed on Silicon Valley's moving onto the next wave of innovation—primarily around Internet technology—was more than the markets could sustain. These markets consist of the financial markets and the consumer markets for Internet products and services, which at the time were embryonic.

The new concentration of activities related to Internet technology suggests that Silicon Valley may never fully regain all the employment lost in recent years. A more weightless Silicon Valley has emerged. Although the average size of the traditional hardware firm in the valley was 200 employees, the average size of its software firms is 27 (Henton, 2000). By 2005, however, the Valley was once again growing in terms of jobs, income, and population, and accounting for more than 10% of patent registrations in the United States (rising from 5% in 1995) (Joint Venture, 2006). This highlights the continuing evolution of the economic and industrial structure of the Valley. During the past 20 years, only 3 of the top 40 Silicon Valley companies—Hewlett Packard, National Semiconductor, and Intel—have remained located in the cluster. The others have failed, relocated, or been replaced by new companies, many of which did not previously exist (A. T. Kearney, 2004).

An important impact of the post-2000 economic environment is the increasing focus of policy makers on the wider Bay Area region of California, covering San Francisco and Oakland, in addition to Silicon Valley (A. T. Kearney, 2004). In the past, Silicon Valley developed along a path that was culturally and economically distinct from the neighboring city of San Francisco, which was not seen as playing any significant role, financial or otherwise, in the operation of Silicon Valley (Rosenberg, 2002). Perhaps as a result of necessity within both camps, there is now an economic and political will to achieve greater integration and connectivity between Silicon Valley and San Francisco. A report funded by regional stakeholders discusses the common challenges and strengths of the Bay Area as a whole rather than focusing just on Silicon Valley (A. T. Kearney, 2004). The report describes the enduring strength of the Bay Area as it continues to be the home of more than one half (54%) of all U.S. biotechnology companies as well as global IT players such as Hewlett Packard, Intel, AMD, Sun Microsystems, Adobe, and Apple and the advanced research centers of IBM, Hitachi, Lockheed Martin, SRI, and Microsoft. The report also highlights issues related to the offshoring and outsourcing of knowledge-based activities to locations outside the Bay Area as an important determinate of the future for the region. For instance, 80% of jobs advertised in the region for quality assurance and test engineers (knowledge-based jobs that are typically the first to be offshored) were for work that would be located outside the Bay Area (A. T. Kearney, 2004).

As part of this process of offshoring and outsourcing, new knowledge clusters are quickly developing in a number of Asian cites and regions, for example, Bangalore, Hyderabad, and Mumbai in India and Beijing, Guangzhou, Hangzhou, Nanjing, and Shanghai in China. These new knowledge clusters and networks are part of the development of a global web of such clusters, at the heart of which is Silicon Valley (Rosenberg, 2002). As an example of such development, international co-patenting in Silicon Valley increased sixfold between 1993 and 2005, with the greatest increase in co-patenting since 2001 occurring with organizations in Bangalore, Shanghai, and Helsinki (Joint Venture, 2007). The changes taking place in the global economy have meant that many firms in Silicon Valley as well as other knowledge-based locations in North America and Europe have shifted and expanded their activities in Asia to improve and sustain competitiveness. For instance, Silicon Valley's Intel has been one of the most active U.S. international R&D investors in recent years. Furthermore, many Asian engineers and entrepreneurs are creating and building networks between Silicon Valley and locations in China and India, transferring knowledge from the West to the East and accelerating the development of key regions such as Beijing, Shanghai, and Bangalore. At the same time, they are providing more cost-effective, yet equally skilled, production processes to firms based in Silicon Valley (Saxenian, 2005).

The policy response to these new patterns of the globalization of the knowledge economy is one of seeking to improve the strength of the knowledge cluster through geographic consolidation and connectivity. As Silicon Valley's policy makers make clear,

> Like other regions, Silicon Valley must find a role to play in a global economy that has become a series of 'value chains' connecting product design, flexible production, marketing, and logistics functions. This is a complex process involving many partners across numerous locations throughout the world. (Joint Venture, 2006, p. 50)

Rather than the "flat" world evoked by Thomas Friedman (2005), these policy makers argue that the world is in fact both flat and "spiked," with the spikes consisting of leading knowledge clusters around the world. Therefore, the perceived challenge for Silicon Valley is

> to recognize our own strengths, identify other regional 'spikes' based on their strengths, and then connect to those 'spikes' for mutual benefit. . . . Although the openness created through global linkages increases exposure to the turmoil of globalization, it also speeds and expands learning by firms and institutions. (Joint Venture, 2007, p. 5)

If Silicon Valley is to continue to compete with emerging but demographically and economically vast knowledge clusters in locations such as India and China, it appears that cluster size and maintaining a significant critical mass are becoming important issues. Therefore, consolidation into a larger Bay Area regional knowledge cluster may be an important first outcome of strategic policy making. However, the challenge this raises is how to transfer attempts to consolidate from the tables of policy makers to those of the strategic decision makers of firms within the region, who are increasingly forming international rather than domestic networks. Cultural differences between working and living environments in Silicon Valley and San Francisco mean that this may not be easily achieved, although cultural convergence is gradually emerging as San Francisco seeks to develop itself as a high-technology hotspot (Indergaard, 2004).

Cambridge (United Kingdom)

In the United Kingdom, the most prominent knowledge clusters are based around the universities of Cambridge in eastern England and Oxford in southeastern England. Cluster development in Cambridge is more progressed than in its Oxford counterpart, with a higher density of cluster actors and networks in Cambridge (Cooke & Huggins, 2003). It is largely informal channels and personal relationships that have shaped the formation of the Cambridge cluster, such as the links between Cambridge University and its spin-off companies. These businesses have emerged from the science base of the university, especially its core strength in the field of early diffusing technologies (Garnsey & Longhi, 2004).

The region of Cambridge is a center of both computer hardware and software, which is continuing to create the localized multiplier effects associated with clusterization. In particular, the university provides important sociocultural preconditions not only for learning but also for the creation of new spin-off firms, interfirm networks, and local scientific and managerial recruitment practices (Garnsey & Heffernan, 2005). The ICT sector accounts for approximately one third of employment in the cluster, with the main activities consisting of application software, electronic equipment, and instruments. IT is also by far the most dominant player in terms of number of firms, accounting for more than 500 of the 900 firms within the knowledge cluster (Library House, 2004).

A key player in the IT field is Advanced RISC Machines (ARM), which, like a number of high-technology ventures in Cambridge, emerged from Acorn Companies and Cambridge's most prominent high-technology entrepreneur, Hermann Hauser. ARM is a leading global licensor of chip technology, which is now an industry standard (Athreye, 2004). ARM began in 1990 as a spin-off from a collaborative venture between Acorn and Apple Computer to create a new microprocessor standard. ARM is now ranked as the number one semiconductor intellectual property supplier in the world. Another prominent IT company is Cambridge Silicon Radio (CSR), which was first listed on the London Stock Exchange in 2004. CSR is a spin-off of Cambridge Consultants, a company that can be traced back and seen as the founding father of the Cambridge knowledge cluster. It was formed in 1960 by a group of former Cambridge University students and acquaintances to "put the brains of Cambridge University at the disposal of the problems of British Industry" (Library House, 2004, p. 5). Through various changes in ownership, the company continues to be a central node in the development of the knowledge cluster, providing specialist research and commercialization expertise across health care and drug delivery, telecommunications, and the automotive and aerospace sectors (Library House, 2004).

Alongside IT, the life sciences sector is the second most important segment of the knowledge cluster, with more than 200 firms and approximately 5,000 employees. Within the sector, biotechnology is the key activity, accounting for more than 100 firms and 4,000 employees. This makes Cambridge the leading U.K. center for biotechnology research and commercialization—followed by Oxfordshire, Surrey, and central Scotland—and is the location for corporations such as GlaxoSmithKline, Wellcome, Merck, Rhone-Poulenc Rorer, and Hoechst.

More than three fourths of firms in the Cambridge cluster possess close links and networks with other local firms (Cooke & Huggins, 2003; Keeble, Lawson, Moore, & Wilkinson, 1999). Cambridge is best known for possessing significant clusterization around university sites such as the Cambridge Science Park and the St John's Innovation Centre as well as a significant number of international R&D establishments. These consist of both publicly and privately funded facilities such as the laboratories of the U.K. Medical Research Council, Hitachi, Microsoft, AT&T, Schlumberger, and Toshiba. In 1998, the networking activities of the cluster became more formalized through the establishment of Cambridge Network Ltd., a company set up to make more visible the linkages between business and the research community, connecting both sets of actors in a more systematic way (Cooke & Huggins, 2003). Also, many of the R&D investments, such as those emanating from corporations including AT&T, GlaxoSmithKline, Hitachi, Intel, Microsoft, Olivetti, Oracle, the Wellcome Trust, and Toshiba, have been made in Cambridge University, resulting in its growth as a leading center of industrial research. As an outcome of these investment patterns, the IT sector is more clustered in its activities than the biotechnology and bioscience sectors, with a large number of interlinked firms spinning off from the university (Cooke & Huggins, 2003).

Cambridge felt the impact of the 2000 downturn, with employment in the knowledge cluster falling by 5% between 2002 and 2004 (Garnsey & Heffernan, 2005). Although the scale of the impact was less than that witnessed in Silicon Valley, it still gave enough of a shock for a major reevaluation of the cluster and its future development (Library House, 2004). As part of this reevaluation, there is now a greater recognition of the role and importance of nonlocal and more global networks across the cluster, which many firms report to be of greater significance to their operations than local networks (Garnsey & Heffernan, 2005). Also, increased attention has been given to the problems encountered as a result of the cluster's being located in a relatively small rural market town, such as the lack of adequate infrastructure and increasing problems of congestion.

These issues have resulted in a number of the cluster's business networks extending their activities into the area of policy intervention (Garnsey & Heffernan, 2005). One of the main issues of concern for those seeking intervention is the contention that Cambridge "can never rival Silicon Valley. But combined with Oxford and the wide swathe between the two university towns it would no longer be a welter-weight" (Rosenberg, 2002, p. 61). As a response, polices are being developed to expand and largely merge the existing knowledge clusters in Cambridge and Oxford. The Oxford–Cambridge Arc initiative has mapped out a geographic area for economic expansion linking both cities. The framework involves creating and attracting knowledge-based investments to newly developed high-technology sites along the 90-mile road corridor between Oxford and Cambridge. The vision is to "create an 'arc' of entrepreneurial activity that would rival Silicon Valley . . . characterised by a spirit of innovation, scientific and technical achievement and entrepreneurship, dedicated to wealth creation through both indigenous growth and inward investment" (SQW Limited, 2001, p. 1). A significant drawback to the realization of the Oxford–Cambridge Arc is the poor infrastructure and transport links between the two cities. As an initial response to a demand for improved and speedy access, a twice-daily air service between Oxford and Cambridge was launched in 2006. Such demand is an indication that the proposed Arc is not just a vision of policy makers but also a reality of increased connectivity across the clusters.

Ottawa

The city-region of Ottawa is Canada's center of high-technology activity, with a knowledge cluster that expanded extensively during the 1990s. During this period, the balance of employment in the region swung from the public sector, which is buoyed by Ottawa's being Canada's federal capital, toward high technology and, in particular, ICT-related employment. Between 1981 and 1996, the share of manufacturing employment involved in high-technology activities rose from 29% to 50%, whereas employment in the government sector fell by 17% (Doloreux, 2004b). At the heart of the cluster are a number of global players in the fields of telecommunications equipment, microelectronics, and software, such as Nortel, JDS Uniphase, Alcatel Canada, Mitel, Compaq Computer, Cognos, and IBM Canada. Of these players, Nortel has been of vital strategic importance to the development of the cluster, with the firm's accounting for approximately one fifth of Canada's total industrial R&D expenditure (Doloreux, 2004b). At its peak, during the early part of the new millennium, the cluster totaled 70,000 employees and was dubbed *Silicon Valley North* because of the rapid growth of companies such as Nortel and JDS Uniphase and the global advantage the cluster achieved in telecommunications, software, photonics, and life sciences (Shavinina, 2004).

The roots of the cluster can be traced to its more mature segment, telecommunications, and the establishment in the region of the National Research Council's (NRC) laboratories, the Communications Research Centre (CRC), and Bell Northern Research, which led to 90% of Canada's R&D in industrial telecommunications being conducted in the region (Wolfe, 2002). Both NRC and CRC have been responsible for spinning off a barrage of knowledge-based ventures in the region, beginning in 1950 with Computing Devices, now General Dynamics Canada. Coupled with Nortel's expansion during the 1970s and 1980s, a series of high-technology entrepreneurs created and grew a number of new telecommunications, microelectronics, and software companies. These entrepreneurs set the stage for the establishment of Ottawa's knowledge cluster, which by the mid-1990s had one of the world's highest per capita percentages of owner-operated high-technology companies (Mallett, 2004).

The development of Ottawa's knowledge cluster is intrinsically linked to three key initial institutional catalysts. First, the cluster benefited from the location of the research facilities of the NRC and the CRC as well as other government laboratories in Ottawa. These institutions have been instrumental in spurring commercial innovation, with many local knowledge-based firms having genealogies linking them with government-developed innovations. Second, the spillovers and spin-offs emanating from Nortel and Bell Northern Research facilities cemented the growth of the cluster. Third, the universities of Ottawa and Carleton have played an important role in creating a significant amount of the knowledge utilized by the cluster's business community. Of these resources, a major overarching factor is undoubtedly Ottawa's federal R&D activities.

Until the early 2000s, Ottawa was a runaway high-technology success story. However, the economic downturn was to bite the region and the knowledge cluster particularly hard. It is estimated that following its employment peak of almost 70,000 in early 2001, more than 20,000 jobs within the knowledge cluster were shed by 2003. Such a large reduction in employment was mainly because of the high number of layoffs at the large corporations, in particular Nortel and JDS Uniphase, which significantly dented the telecommunications and photonics segments of the cluster (Wolfe & Gertler, 2004). Somewhat fortunately, a large proportion of the unemployment was mopped up by the public sector, which took on an extra 13,000 employees and ensured a stream of public sector procurement contracts to local knowledge-based firms. Other individuals laid off were forced into necessity-based entrepreneurship, which ironically meant that even though the employment size of the cluster was much reduced, the number of firms increased, with an estimated 400 new knowledge-based ventures created (Jackson & Khan, 2003).

Despite the efforts of the government to limit the economic and social fallout of the downturn, a major readjustment of Ottawa's knowledge cluster and its future trajectory resulted. In the past, the vitality of the cluster was credited to the strong intraregional networks and their effectiveness in transferring and commercializing locally created knowledge. More recently, increased emphasis has been given to the role and importance of knowledge networks with actors that are external to the region and the cluster. Although local networks continue to provide mechanisms for transferring knowledge within the cluster, it has been found that the most important sources of knowledge and innovation for small and medium-sized enterprises in the cluster are global knowledge networks (Doloreux, 2004a). Also, at the large firm level, Nortel and JDS Uniphase have established their own global knowledge networks through growing a distributed system of innovation and knowledge flow (de la Mothe, 2003).

As an outcome of economic readjustment, policy makers in Ottawa are setting in place initiatives to globalize their national and regional knowledge economies. Since 2004, international cooperation agreements have been instigated between Canada and India to facilitate increased trade and business in the ICT sector. Also, the Canadian Advanced Technology Alliance, the China Chamber of International Commerce, and the Shenzhen High-Technology Industrial Association (Shenzhen being the home of one of China's rapidly emerging ICT clusters) have entered agreements to develop business networks in the high-technology field. These agreements and other related initiatives point to a realization in Ottawa of the emergence of the global knowledge economy and the necessity to become players in this economy's networks. In April 2005, Ottawa's knowledge cluster achieved its first IPO in 6 years, when March Networks was floated on the Toronto Stock Exchange, with its success attributed to its ability to compete in global rather than local or national markets. This outward orientation represents the next phase in the evolution of Ottawa's knowledge cluster.

Helsinki

The Helsinki region is the core of Finland's knowledge economy. Nine out of the top 10 Finnish companies are located in the region. This list is dominated by Nokia, which employs 10,000 people in the Helsinki region (approximately 20% of its total global workforce) and has driven forward the development of a knowledge cluster rooted in ICT and related activities. It has also taken a lead role in creating linkages and networks with businesses and research establishments in the region (van der Meer, van Winden, & Woets, 2003). Many of the components of the national innovation system are also located in the region, which is the location for 42% of the business R&D undertaken in Finland. The University of Helsinki accounts for approximately one fifth of R&D undertaken by the nation's universities, with 35% of all university R&D spending in Finland occurring within the region (Steinbock, 2006). In total, 80% of the country's wireless technology companies are located in the region. This allows them to remain close to Nokia and other important players such as Sonera and Radiolinja. Both public and private R&D investment has supported the globalization strategy of Nokia, which has established a vertically integrated and strongly specialized sector in the region (Roper & Grimes, 2005).

During the 1990s, Finland followed a different path from most other industrialized nations. Although many nations experienced either stagnating or declining R&D funding, government funding for R&D in Finland increased by approximately 40% between 1995 and 1999. From 2001 onward, the economic landscape and long-term outlook for Finland has looked less assured than it did during the late 1990s, particularly with the slowing down of the mobile telecommunication markets. The benefits Finland received through Nokia's first-mover advantage in the mobile telecommunications sector meant that the national economy became increasingly dependent on the company and its operating sector. It is estimated that Nokia ultimately generates one third of Finland's economic activity, either directly or through its supplier network, and accounts for almost three fourths of the market capitalization of the Helsinki Stock Exchange (Rosenberg, 2002; Steinbock, 2006).

Finnish policy makers increasingly view the pervasiveness of Nokia as a negative feature of their economy and seek greater diversification, which integrates Nokia's success with a realization of the need for a wider scope of industrial activity beyond mobile telecommunications. Although Nokia is now fully engaged in a globalization strategy that extends far beyond its base in Helsinki's knowledge cluster, with R&D centers in China, India, and the United States, the remainder of the cluster is no longer the engine of growth it once was. The cluster and its specialization in ICT-related activity are depicted as introducing considerable vulnerability to the Finnish economy, particularly as the demand for mobile phone technology switches from original to replacement demand (Holstila, 2004). Therefore, the maturation of the sector is resulting in price erosion, which in turn is eroding the strength of the cluster (Steinbock, 2006). Policy makers in the Helsinki region are now embarking on a more radical course of diversification and internationalization as a means of reinvigorating the knowledge cluster. More support and promotion are being given to knowledge-based service sector activities as opposed to the current cluster bias toward technology-oriented manufacturing. Also, there is an ambitious plan to form a wider knowledge cluster with the city of Tallinn, the capital of Estonia, a former Soviet Union country that joined the European Union in 2004.

The knowledge cluster development with Tallinn, which is situated a short distance across the Gulf of Finland, is partly an effort to replicate the strategic alliance forged to connect the Copenhagen region in Denmark to the Skåne region (southern part of Sweden), including the cities of Malmö and Lund in Sweden, by linking their respective biotechnology clusters to form a joint venture known as Medicon Valley. As a result of the relative isolation of much of its industry and economic activity, with the exception of Nokia and its collaborators, Finnish policy makers have become steadily interested in the possibility of connecting existing clusters both within and beyond national boundaries.

In the case of the Helsinki–Tallinn knowledge cluster, it is primarily the scientific research emanating from the universities in each region that is seen as representing the initial possibilities to create this drift, covering biomedicine and biotechnology, ICT, materials science, and related new technologies. Estonia, and Tallinn in particular, have embraced the information society and have geared their economic and industrial policies toward the creation of a sustainable knowledge-based economy. An important feature of these policies is the commercialization of the rich output from their technology and science institutions, a positive legacy dating back to the Soviet era.

Like Oxford and Cambridge, regional policy makers consider each region alone to be too small to compete separately at the global level. Tallinn, like Helsinki, has a strong technical university plus a number of other research institutions, and a benchmarking of both regions indicates significant scope for complementary knowledge transfer, primarily in the areas of ICT and biotechnology (Bison, Dubois, Dymèn, Ezaz, & Murray, 2004). At present, however, the level of transfer and collaboration is limited (Hydrios Biotechnology Ltd., 2004). This suggests that very significant resources will be required to create a functioning cross-regional knowledge cluster capable of producing a "coherent area of science, education and high-tech business in the future" (Bison et al., 2004, p. 6). A potential drawback to connected cluster development is the unevenness of existing business relationships between firms in Helsinki and Tallinn. Firms in Helsinki often use Tallinn businesses for subcontracting purposes, a process not always conducive to creating parity in knowledge flow (Bison et al., 2004).

The cluster initiative currently lacks significant corporate sector involvement, although Finland is the most significant foreign investments in Estonia, with Tallinn being the location for most investment. Investment has initially occurred to take advantage of the labor cost differential between Finland and Estonia. If these investors increase their embeddedness in the region, there is a possibility they may act as catalysts of increased linkage. Potential long-term stimulators of Helsinki–Tallinn cluster development are the historical ties between Finland and Estonia. There is a deep cultural and economic bond in the form of the closeness of languages and trade across Estonia, Finland, and other Baltic and Scandinavian countries, which existed long before Estonia gained its independence from the former Soviet Union. Overall, Finland has played and will continue to play an integral role in the economic development of Estonia. Whether this extends to the connection of the knowledge economies of their capital regions remains to be seen.

Knowledge Cluster Development

In his classic 1955 article, Francois Perroux (1955) argued that in the end "scale" and "innovation" are the predictors of success, whereas Albert Hirschman (1958) recognized the role of interdependence and linkages across related sectors in achieving economic growth. The processes of consolidating and connecting knowledge clusters is a manifestation that these principles are reemerging as key tenets of change in today's global economy. In particular, some of the world's most visible knowledge clusters are operating networks that are more open, as they seek new knowledge and the means to more efficiently exploit their existing knowledge base (Britton, 2004). In Silicon Valley, cluster actors utilize the benefits of proximity to build and manage global-scale production networks (Sturgeon, 2003). In the United Kingdom, national and international networks are just as significant as their local counterparts for fostering innovation (Simmie, 2004). The key aspect of these developments is that the knowledge base of the world's most advanced local and regional economies is no longer necessarily local, but positioned within global knowledge networks, connecting clusters and their actors (Wolfe & Gertler, 2004). Furthermore, national innovation systems are becoming more "leaky" over time, whereby "the role of tacit knowledge and the spatial limits on knowledge spillovers have caused firms to locate R&D facilities where new knowledge is being created" (Carlsson, 2006, p. 65).

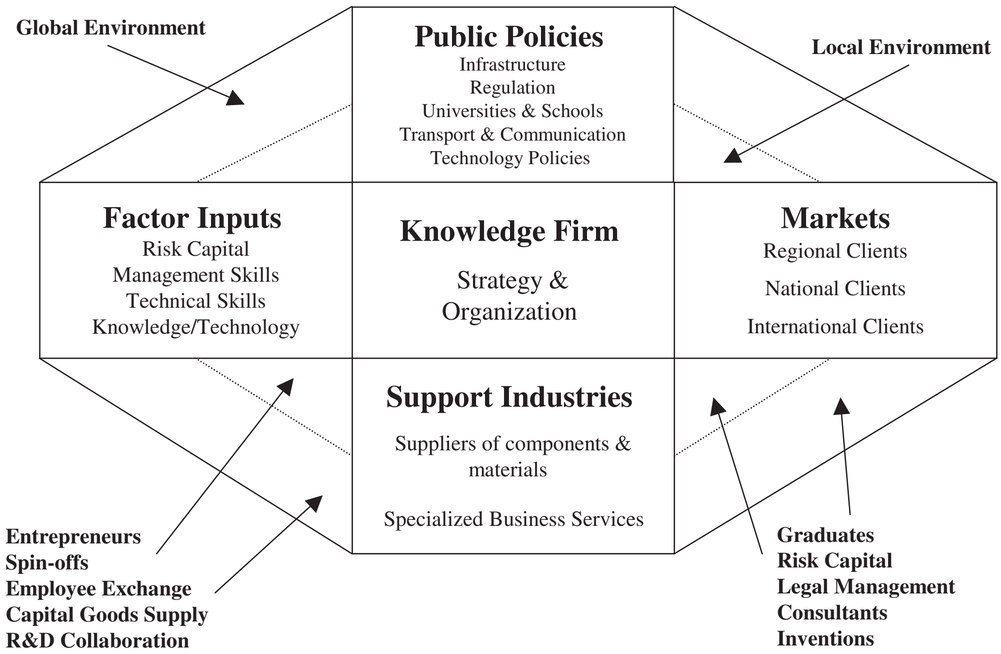
The constraining effect of distance on knowledge flow and transfer is gradually diminishing (Johnson, Siripong, & Brown, 2006). Furthermore, in the postbubble world there is an increasing recognition that knowledge clusters are susceptible to problems if there is little diversification in the type of knowledge the cluster is creating and seeking to commercialize (Gittell & Sohl, 2005). As a result, knowledge cluster policy making is quickly seeking to shift itself toward more open and connected systems. According to Storper (1995), "in evolutionary economics, what we do is path-dependent, that is truly historical; it is not the result of a series of actions on spot markets, where the long-term can be disconnected" (p. 204). Similarly, regional knowledge clusters are not accidental market creations but the result of planned communities of knowledge production, which in the case of U.S. knowledge clusters such as Silicon Valley consist of research universities and their role at the heart of cold war defense activity (Pugh O'Mara, 2004). Knowledge-based development is the product of interdependent choices predicated by the existing systems of networks. It is the system of networks within knowledge clusters through which technological spillovers and untraded interdependencies—or the linkage reliance between cluster actors beyond the market—are channeled and communicated (Fleming & Marx, 2006). This facilitates knowledge-cluster actors to travel along "superior technological trajectories" (Storper, 1995). However, knowledge clusters, like products, have a limited lifecycle. Those clusters able to renew themselves and evolve through innovation develop a morphological capacity to remain comparatively competitive through periods of national or global recession.

Clusters must themselves be subject to innovation, dynamic change, and evolving processes in much the same way that products have to change if they are to diminish the risk of having a short shelf life. Audretsch (1998) suggests that "the role of tacit knowledge in generating innovative activity is presumably the greatest during the early stages of the industry life cycle, before product standards have been established and a dominant design has emerged" (p. 23). This indicates the high potentiality for the overlap of cluster evolution with industrial and product life cycles and trajectories. This argument is proven by the clusterization and declusterization of traditional industries as a direct result of product and technological change.

The requirements for specialized technological research, supply, and servicing mean that knowledge industries are bound by a specific knowledge base, limiting the number of locations within which such development across the globe has so far occurred. Figure 2 summarizes the complex local and global environment within which knowledge-based firms operate, the two broad schools of thought regarding spatial proximity and knowledge. The first school argues that proximity is a significant mechanism for generating collaborative innovation. The second suggests that connectivity through global spaces is a more important stimulant of technological advancement. These two poles introduce an unnecessary divide of global and local forces when the reality suggests that for firms in knowledge clusters both forces are operating in an overlapping manner. Successful connectivity in global spaces is often the outcome of an initial system of localized interaction, whereby it is the knowledge crossing hallways and streets that initially catalyzes intellectual exchange and knowledge transfer across oceans and continents (Glaeser, Kallal, Scheinkman, & Shleifer, 1992).

Although it is undoubtedly impossible to replicate or clone regions such as Silicon Valley, or any other knowledge cluster for that matter, there are many lessons that can be learned about how to improve the competitiveness of regional locations, in particular the role networks have played in making regions with strong knowledge clusters the centers of global growth. At the same time, it is important to recognize that such clusters should not be

Figure 2
The Knowledge Firm and Its Environment



Note: The figure is based on an earlier typology of factors developed by Tödtling (1994).

viewed as utopian because, like firms, the challenges involved in their creation and sustainability are contingent on a set of factors related to prevailing local and global forces. For instance, the past failure of many science parks as a policy response for generating high-technology activity can be strongly related to the fact that although they facilitated the co-location of companies, such policies ignored the processes through which this co-location could be activated into meaningful interaction and collaboration, particularly between industry and academia. It has long been argued that most science park developments are no more than high-tech fantasies, contributing little to increased links between industry and the academic world (Massey, Quintas, & Wield, 1992).

Cluster development policies directly mirror the incentive to develop networks between firms. They reflect the desire of firms to lower the transaction costs of traditional market exchanges or cumbersome hierarchies. Networks and clusters have both become increasingly important as firms downsize and outsource many of their noncore activities. The overall effect of this is an extension of the value chain, as firm specialization and resource concentration become the axis of competitive advantage acquisition. This specialization has rapidly pushed the value of network resources higher up the ladder of strategic resources employed by firms (Gulati, 1999).

As an aid to both business strategy and public policy making, it is useful to develop a route map outlining the generic evolution of knowledge clusters, as shown by Table 1. From this map the key evolutionary stages can be summarized as follows:

Genesis: The creation of knowledge clusters is inevitably related to an institutional trigger. Institutional triggers act as an initial magnet for attracting talent, and although they may not necessarily be a singular institution there is a high degree of correlation with the existence of specific universities and research institutes (Harrison, Cooper, & Mason, 2004). Triggers are institutional in the sense of there being a set of preexisting relationships or associations. The primary feature of institutional triggers consists of the existence of social networks, high trust, strong ties, and localized linkages.

Development: The initial developmental phase of a knowledge cluster is based on forces that spin off knowledge from the institutional trigger, which remains localized. The existing relationships held by the institutional trigger—based on informal networks with frequent contact and dense ties—are proactively utilized to push out new entrepreneurs and spin off firms that create new relationships and collaborations between both themselves and the existing institutions.

Table 1
The Evolution of Knowledge Clusters

Stage of Evolution	Cluster Force	Key Actors	Network Types	Network Ties
Genesis	Institutional trigger	Institutional trigger	Local linkage, social networks	High trust, strong ties
Development	Centrifugal forces	New entrepreneurs and spin-offs	Informal networks	Dense ties, frequent contact
Growth	Centripetal forces	New knowledge investment, venture capital, business service firms	Formal networks, strategic alliances	Global ties
Renewal (demise)	Knowledge trajectories	New skilled workers creating new products and markets	Integrated new modes of interaction	Indirect ties

Growth: Knowledge clusters that successfully develop a critical mass act as a centripetal magnet for new capital inputs in the form of inward investing knowledge-based firms, venture capital organizations, and other firms specializing in specific business and professional service activities. At this stage, the scope of existing relationships evolves with the creation of more formalized networks and strategic alliances, particularly through the generation of new ties beyond the cluster.

Renewal (demise): The final stage of a knowledge cluster's initial life cycle is dependent on the technological trajectory or path of its product and process base. Clusters able to adapt to disruptive knowledge shifts through the creative destruction associated with new product and market development will survive and grow, whereas those clusters that have become overly path dependent will eventually die. Perhaps the most important feature is the requirement for the continual development and mobilization of human capital. At the renewal stage, this is strongly related to the capacity to renew networks and create new modes of interaction, often with actors who are one step removed—indirect ties—from existing associations.

Conclusions

Most knowledge-cluster-development policies across the globe have focused far too much on the structural products of development—especially hard infrastructure—to the detriment of the functional processes, for example, the networks and the value and supply chains underlying successful growth. It is not difficult to understand the reason for this, as because it is far easier to "see" and replicate structures than it is to understand and apply the lessons of facilitating softer infrastructure such as networks and collaborations. However, replication is no guarantee of cluster success, as clusters vary across industries, location, and operating dimensions, meaning there is no one set of policies that will make a cluster successful (Cortright, 2006). For some, the problem is the result of policy makers becoming seduced by the cluster concept without sufficient understanding of its fundamental underpinnings (Martin & Sunley, 2003). In some circumstances, this has led to cluster policies being no more than gimmicks attempting to justify badly conceived government interventions (Rosenfeld, 2005). Cluster policies inherently concern the development of relationships, exchange, and interaction by facilitating the generation of communication networks.

Although many cluster policies have almost completely ignored the network aspect of cluster building, those policies containing such an aspect have usually focused on stimulating new connectivity at the local and regional level. The evidence from the case studies in this article indicates that leading knowledge clusters are adapting their approaches to network building by seeking greater connectivity at the global level or heightened critical mass through consolidation with other relatively proximate clusters. This does not demote the importance of localized network building at the genesis of cluster building. However, as the evolutionary process from genesis to renewal or demise becomes ever shorter, it strongly suggests that new clusters should simultaneously position themselves in a more global network environment.

Notes

1. Some of the key competitive advantages of cluster formation include the following: lowering transaction costs, accessing new and complementary knowledge, capturing economies of synergy and interdependent activities, spreading risks, promoting joint R&D efforts with suppliers and users, obtaining reciprocal benefits from the combined use of complementary assets and knowledge, speeding up learning processes; and overcoming (or creating) entry barriers to markets.

2. Paul Krugman (1994) contends that, given a slightly different sequence of events, Silicon Valley might have been in Los Angeles, Massachusetts, or even Oxfordshire.

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