11 Spaces of knowledge flows

Clusters in a global context

Meric S. Gertler and David A. Wolfe

Is all knowledge local?

At the very foundation of the cluster concept is the idea that proximity matters. The literature suggests that this is manifest in a number of important ways. First, the geographical clustering of economic actors facilitates the exchange of knowledge between them, through both traded and untraded means. The interaction that supports this is formal and planned as well as informal or unplanned, with spatial concentration facilitating both forms of contact. Common conventions and norms, and readily available knowledge about the reliability and trustworthiness of individual economic actors, further support the local flow of knowledge – both tacit and codified – within local industry clusters (Storper and Leamer 2001; Storper and Venables 2004). The same conditions enrich close, collaborative vertical interaction with local customers and suppliers, in which learning-through-interacting generates mutual benefits for technology users and producers alike (Lundvall 1988; Gertler 1995). Finally, the geographical clustering of firms in the same industries accentuates competition – and the innovative dynamism arising from it – by enhancing firms' ability to learn from one another through observation and monitoring (Porter 2000; Malmberg and Maskell 2002).

While the above picture represents a coherent and influential consensus view emerging from the cluster literature, it is not free of controversy (Martin and Sunley 2003). Recent conceptual contributions to the literature have begun to propose the unthinkable: to question the overwhelming emphasis on local interaction and knowledge circulation contained within the cluster as the only – or even the primary – source of innovative dynamism for firms in clusters. Instead, these recent commentaries argue that non-local (inter-regional and international) relationships and knowledge flows are crucial sources of vitality, complementing the local 'buzz' that has come to be regarded as the hallmark characteristic of the cluster (Bathelt et al. 2004; Owen-Smith and Powell 2004). Appealing as these arguments may be, however, they still rest on a small base of empirical evidence.

This chapter aims to address this gap in our knowledge and understanding by synthesizing the results of an ongoing comprehensive national study of cluster

development in Canada. The study covers a range of economic sectors – both mature and new – as well as different types of geographical locations: large metropolitan regions as well as mid-size urban regions and rural settings. We provide an analytical overview of the findings from this study, and use it to shed light on the relative importance of local and non-local actors, relationships, and forces in the development of more innovative forms of production. We also build a conceptual typology, based on types of knowledge, institutional frameworks, and the strength of geographical concentration of economic actors. In this way, we aim to make a larger contribution to ongoing debates concerning the importance of the local in the development of economic clusters.

The economic advantages of clusters: agglomeration and knowledge spillovers

According to the large literature on the subject, the potential advantages that firms derive from locating within clusters arise from two principal sources: agglomeration benefits and knowledge spillovers. Agglomeration economies arise primarily from the ready access to a collective set of resources available to firms co-locating in the same region or locale. Porter's (2000) work is consistent with this approach, although he embellishes the benefits attributed to traditional agglomeration economies by setting out the competitive advantages derived from the effects of his 'diamond'. Porter stresses that the location of a firm within the cluster contributes to enhanced productivity, higher wages, and greater innovativeness by providing easier and/or cheaper access to specialized inputs, including components, machinery, business services, and personnel, whose availability obviates the need for vertical integration or non-local sourcing of necessary inputs. Local sourcing from within the cluster also facilitates communication with key suppliers in the sense that repeated interactions with local supply firms in the value chain creates the potential for conducting repeated transactions on the basis of tacit, as well as more codified, forms of knowledge. Clusters offer distinct advantages to firms in terms of the availability of specialized and experienced personnel. The cluster itself can act as a magnet drawing skilled labour to it. Conversely the location of specialized training and educational institutions in the region provides a steady supply of highly qualified labour to the firms in the cluster.

While not diminishing the importance of these agglomeration economies, another stream of literature suggests that a key source of competitive advantage for firms located in clusters is their shared access to a distinctive local knowledge base. The central argument is that the joint production and transmission of new knowledge occurs most effectively among economic actors located close to each other. Proximity to critical sources of knowledge, whether they are found in public or private research institutions or embedded in the core competencies of lead or anchor firms, facilitates the process of acquiring new technical knowledge, especially when the relevant knowledge is located at the research frontier or involves a largely tacit dimension. Knowledge of this nature is

transmitted most effectively through interpersonal contacts and the inter-firm mobility of skilled workers. However, Breschi and Malerba (2001) argue that this approach overestimates the benefits of physical proximity alone. They argue that sheer proximity is not sufficient to account for local knowledge spillovers. In their view, the body of research on local knowledge spillovers overlooks the broader set of factors and conditions that support the effective transfer of knowledge in clusters: 'a key feature of successful high-technology clusters is related to the high level of embeddedness of local firms in a very thick network of knowledge sharing, which is supported by close social interactions and by institutions building trust and encouraging informal relations among actors' (Breschi and Malerba 2001, 819).

In other words, the degree to which firms can tap into a common knowledge base at the local level depends on more than just spatial proximity, cultural affinity, or corporate culture. In this sense there is a strong interdependence between the economic structure and social institutions that comprise the cluster. The institutional context of the cluster defines how things are done within it and how learning transpires. As Gertler has argued, it is a function of institutional proximity – the common norms, conventions, values, and routines that arise from commonly experienced frameworks of institutions existing within a regional setting (2003; 2004).

It is also critical to differentiate between different kinds of knowledge spillovers. Much of the literature on knowledge spillovers, and in particular the role of tacit knowledge, presumes that the knowledge being shared is highly technical in nature and results largely from the transfer of research results between regionally embedded research institutes and private firms. However, technical research results are only one element of the kinds of knowledge flows that contribute to the competitive dynamics of a successful cluster. One of the most important forms of knowledge flow is the knowledge embodied in highly qualified personnel which flows directly from research institutes to private firms in the form of graduates and also moves between firms in the form of mobile labour (Wolfe 2005). There is a strong suggestion in the literature that the re-combination of talent in new configurations through labour mobility and the spinning off of new start-up firms is one of the most important sources of innovative dynamism in clusters (Saxenian 1994; Brown and Duguid 2000).

Another form of knowledge flow involves entrepreneurial skills. Feldman et al. place this form of knowledge flow at the centre of their model of cluster formation. Entrepreneurs act as the key agents who build upon the existing base of institutional assets that provide the local antecedents for cluster formation. In their view, an outbreak of entrepreneurial activity is necessary to transform these assets into a cluster (2005). From our perspective, the ongoing transmission of entrepreneurial skills within the cluster is critical for its continued vitality and growth. This form of knowledge can be transmitted through a variety of mechanisms – including the spinning off of new firms from large anchor firms within the cluster, the mobility of key personnel within the cluster, and the transfer of entrepreneurial and managerial skills through angel and venture

investing. Closely related to this is knowledge about external market conditions. For small and medium-sized enterprises, an essential piece of knowledge they must acquire to grow and expand concerns the competitive conditions in external markets and which ones constitute the most suitable targets for expansion. Entrepreneurial skills and market information can be transmitted throughout the cluster by a variety of mechanisms – some formal and some informal. One of the most important is the peer-to-peer mentoring and knowledge-sharing that is organized through local industrial and civic associations. The dynamic role played by such associations in facilitating this form of knowledge flow underlines the importance of the local and regional institutional structures. The final dimension of knowledge-sharing crucial for the success of the cluster is achieved through the infrastructural knowledge resources found in the specialized local legal, management, and financial firms that are essential to the success of individual firms in the cluster. These kinds of services often provide vital support to the individual firms in the cluster.

In an attempt to elaborate further the role that knowledge plays in sustaining clusters, Maskell (2001) has proposed a knowledge-based theory of the cluster. He suggests that the primary reason for the emergence of clusters is the enhanced knowledge creation that occurs along two complementary dimensions: horizontal and vertical. Along the horizontal dimension, clusters reduce the cost of co-ordinating dispersed sources of knowledge and overcoming the problems of asymmetrical access to information for different firms producing similar goods and competing with one another. The advantages of proximity arise from continuous observation, comparison, and monitoring of what local rival firms are doing, which drives innovation as firms race to keep up with or get ahead of their rivals. The vertical dimension of the cluster consists of those firms that are complementary and interlinked through a network of supplier, service and customer relations. Once a specialized cluster develops, local firms increase their demand for specialized services and supplies. Furthermore, once the cluster has emerged, it acts as a magnet drawing in additional firms whose activities require access to the existing knowledge base or complement it in some significant respect (Maskell 2001, 937). In critical respects, this knowledge-based conception of the cluster takes for granted key aspects of the Porter diamond, by assuming that firms co-located in the cluster tend to be rivals in the same product markets or part of a locally based supply chain, and that close monitoring of competitors or tight buyer–supplier interaction are key elements that tie the firm to the cluster. While these conditions may hold for the most developed clusters in their respective industrial or product segments, there is growing evidence (see following sections of this chapter) to suggest that they do not apply universally to all clusters – especially those in more specialized niches, at an earlier stage of development, or in smaller, more open national economies.

If Porter's conditions do not hold, then this opens up a new line of inquiry about the relationship between the global and the local, and complicates considerably the question we posed at the outset: must local concentrations of

firms in the same and related sectors rely exclusively on local sources of knowledge? A knowledge-based theory of the cluster must recognize that relatively few clusters are completely self-sufficient in terms of the knowledge base from which they draw. The development of ever more complex technologies, such as modern passenger aircraft, requires the support of sophisticated organizational networks that provide key elements or components of the overall technology (Kash and Rycroft 2000). While some elements of these complex technologies may be co-located in an individual cluster, increasingly the components of these networks are situated across a wide array of locations (Niosi and Zhegu 2005). This suggests that the knowledge flows that feed innovation in a cluster are often both local and global. Bathelt et al. (2004) maintain that successful clusters are those that are effective at building and managing a variety of channels for accessing relevant knowledge from around the globe. However, the skills required to absorb knowledge from the local environment are substantially different from the ones needed to identify, acquire, and make the best use of knowledge produced elsewhere, and firms in the cluster must be able to manage these different tasks. Bathelt et al. maintain that a robust knowledge-based model of the cluster must account for both dimensions of these knowledge flows.

Bathelt et al. refer to these two kinds of knowledge flows as *local buzz* and *global pipelines* respectively. Following Storper and Venables (2004), 'buzz' arises from the fact of physical co-presence. It incorporates both the broad general conditions that exist when it is possible to glean knowledge from intentional face-to-face contacts, as well as the more diffuse forms of knowledge acquisition that arise from chance or accidental meetings and the mere fact of being in the same location. Buzz is the force that facilitates the circulation of information in a local economy or community and it is also the mechanism that supports the functioning of networks in the community. In this context, it is almost impossible to avoid acquiring information about other firms in the cluster and their activities through the myriad number of contact points that exist. Pipelines, on the other hand, refer to channels of communication used in distant interaction, between firms in clusters and knowledge-producing centres located at a distance. Important knowledge flows are generated through network pipelines. The effectiveness of these pipelines depends on the strength of pre-established social relationships and the quality of trust that exists between the firms in the different nodes involved. The advantages of global pipelines derive from the integration of firms located in multiple selection environments, each of which is open to different technical potentialities. Access to these global pipelines can stimulate new local innovation through the use of knowledge that has contributed to the emergence of successful firms and clusters elsewhere. Firms need access to both local buzz and the knowledge acquired through international pipelines. The ability of firms to access such global pipelines and to identify both the location of external knowledge and its potential value depends very much on the internal organization of the firm, in other words, its 'absorptive capacity'. The same can be said of local and regional clusters (Bathelt et al. 2004).

However, the precise mix of the global and local knowledge flows present in individual clusters must of necessity be indeterminate. There is increasing evidence to suggest that, even in the most advanced clusters, a growing proportion of the knowledge base is not exclusively local. Recent work on Silicon Valley indicates that local production processes are part of a complex production chain that is connected into global production networks. The most dynamic of multinational corporations and a larger proportion of emerging small and medium-sized enterprises have strong linkages to a variety of specialized clusters around the globe. Both types of firms use their presence in these local clusters to access specialized bodies of knowledge created by the local research institutions, or to tap into a specialized skill set or knowledge base developed by cluster-based firms. However, rarely are the local knowledge bases of these clusters, or the production activities of the firms embedded in them, completely self-contained. Rather, according to Sturgeon, 'what gets worked out in the clusters is exactly the codification schemes that are required to create and manage spatially dispersed but tightly integrated production systems' (Sturgeon 2003, 200). A greater proportion of the production of complex technologies in sectors ranging from information technology to the aircraft and automotive assembly occurs in these 'modular production networks' with activities dispersed across a wide range of global locations. What take place in the clusters of the more industrialized economies are the core interactions between lead firms and key suppliers that resist easy codification, such as design, development of prototypes, and determining the validity of manufacturing processes. The production of high value-added or low-volume products also takes place in these locations. Sturgeon implies that there is a geographic hierarchy of clusters within specific industrial sectors, with Silicon Valley acting as the key location for standard-setting activity in information technology (Sturgeon 2003, 220).

A marked pattern of stronger global (versus local) relations emerges even more clearly in a recent study of opto-electronics clusters in six locations (Hendry et al. 2000). This study found that extra-regional commercial linkages are more important than localized ones, owing to the highly diversified nature of the end-user markets and the complexity of the technologies involved in assembling an end product for the market. The individual clusters in each of the six regions are dominated by a key local actor: either a strong research centre or a lead firm that serves as a catalyst to bring together the firms in the cluster. However, owing to the nature of the technologies involved and the intra- and inter-firm dynamics, there is little local co-operation and few traded relationships among firms within the individual clusters. What the firms in the clusters do share is their common linkage to the leading institution or firm and their common interest in stimulating and maintaining the critical supply of highly skilled labour (Hendry et al. 2000, 140–1).

These findings are consistent with a number of objections that have been raised with respect to Porter's assertions about the critical importance of local factor and demand conditions for the development of clusters. As noted earlier, one of the key sources of knowledge – especially in an era in which nonlinear,

interactive innovation processes have become widespread – is the customer or user. While there is a widespread acceptance within the cluster literature that the most demanding customers – Porter's oft-repeated 'sophisticated and demanding' customers (Porter 2000, 258) – must necessarily be local for competitive industries and clusters to emerge, this assertion is contradicted by a growing body of both analytical and empirical research. A number of management scholars question whether the home market is as critical for the emergence of competitive industries and economies as Porter insists. They note that Porter's original analysis in *The Competitive Advantage of Nations*, which was conducted at the level of the national economy, drew overwhelmingly on the US case – a large, affluent, and diverse domestic market that is likely to contain a high proportion of linkages to customers within the same country. They draw upon the international trade and other bodies of literature to note that these conditions seldom hold to the same extent in small, open trading economies – such as Canada or the Scandinavian economies, which are tightly linked to larger trading partners (Davies and Ellis 2000, 1202–4). The emphasis on local demand conditions holds up even less well when it is transferred to the local and regional level, where the very definition of the cluster's boundaries is highly problematic. As Martin and Sunley note, the definition of the local in much of the work on regional clusters is highly elastic (2003, 11). A growing body of evidence suggests the primacy attributed to local demand conditions may be less than universal. Malmberg and Power document numerous cases in which non-local demand dominates industrial markets (2005a).

Cluster dynamics and industrial knowledge bases

We suggest that a great deal of the confusion surrounding the importance or unimportance of spatial proximity to the innovation process arises from the failure to differentiate between different types of knowledge that underlie innovative products and processes. For certain industries, reliant on particular forms of knowledge and learning processes, proximity between firms and their customers, suppliers, and competitors will logically be essential; for others, this mutual attraction may indeed be far less powerful. It is therefore useful to have a clearer understanding of how these forms of knowledge might vary systematically between industries.

The recent literature in economic geography and evolutionary economics makes the (by now) well-known distinction between tacit and codified forms of knowledge (see Gertler 2003 for a recent review of this literature and related debates). The argument in a nutshell is that, because tacit knowledge is – by definition – more difficult to share in written, symbolic form, and because it is strongly context-specific, it tends to be more commonly transmitted through direct face-to-face (F2F) interaction. Consequently, those firms and industries for which innovation depends heavily on tacit knowledge transmission and application will tend to cluster spatially with their customers, suppliers, and competitors. Conversely, those firms and industries in which codified forms of

knowledge are relatively more important will be less constrained spatially to cluster in this way. In other words, local 'buzz' dynamics will be less powerful than the reach of global 'pipelines'.

Compelling as this distinction may appear, it has been criticized from a number of angles that are relevant to the current discussion. First, as Nonaka and Takeuchi (1995), Nonaka et al. (2000), and Johnson et al. (2002) point out, the process of producing and using new knowledge involves a dynamic interplay between, and transformation of, tacit and codified forms of knowledge in virtually all sectors of the economy. In other words, these two forms of knowledge are complements to, not substitutes for, one another.

Second, Pavitt (1984), Malerba (2005), and others have argued that knowledge bases tend to vary systematically by industry – and so too does the nature of the innovation process. It therefore stands to reason that the geography of knowledge flows – within and between local clusters – will also exhibit characteristic patterns by sector. Recent analyses of this question have found the distinction between 'analytical' and 'synthetic' knowledge bases (Laestadius 1998) to be helpful in this regard (see Coenen et al. 2004; Asheim and Gertler 2005).

A *synthetic* knowledge base dominates industrial settings where innovation takes place mainly through the application or novel combinations of existing knowledge. Innovation in such industries tends to be driven by the need to solve specific problems arising in the interaction with clients and suppliers. Classic industry examples come from sectors within advanced industrial engineering (such as the development of specialized machinery). In such sectors, research is less important than development. When it occurs, it tends to take the form of applied research, but the most prevalent form of innovative activity is what might be described as incremental product or process development to solve technological or production problems presented by customers. Knowledge tends to be created inductively rather than deductively, through a process of testing, experimentation, and simulation. While the knowledge embodied in technical solutions is at least partially codified, tacit knowledge tends to be more important, since shop floor or office experience, on-the-job training, and learning by doing, using, and interacting are crucial to knowledge generation. Much of this knowledge resides in concrete know-how, craft, and practical skill.

In contrast, in those industries where scientific knowledge is highly important, and where knowledge creation is normally based on formal models, codified science, and rational processes, an *analytical* knowledge base is dominant. Obvious examples of such industries are biotechnology and the ICT sector. Here, the core activity generating new products and processes is systematically organized research and development, both inside the individual firm and in collaboration with universities and other research organizations. Knowledge inputs and outputs in this type of knowledge base are more often codified (or readily codifiable) than in the case of synthetic knowledge, although this does not mean that tacit knowledge is unimportant since – as noted above – both kinds of knowledge are always involved in the innovation process. As

Asheim and Gertler (2005) note, the predominance of codification is due to several factors:

> knowledge inputs are often based on reviews of existing studies, knowledge generation is based on the application of widely shared and understood scientific principles and methods, knowledge processes are more formally organised (e.g. in R&D departments) and outcomes tend to be documented in reports, electronic files or patent descriptions.

Knowledge outputs are most frequently in the form of new products or processes, which are more likely to constitute radical rather than incremental innovations.

Of course, just as all innovation processes make use of both tacit and codified forms of knowledge, so too do many industries draw significantly upon *both* synthetic and analytical forms of knowledge. A case in point is the medical devices and technologies sector, in which product development draws upon knowledge from a wide range of fields including bioscience, ICT, software, advanced materials, nanotechnology, and mechanical engineering. Accordingly, it makes more sense to locate individual industries along a spectrum between purely analytical and synthetic knowledge bases, with many – such as the automotive industry – occupying an intermediate position along this continuum.

How might this distinction between synthetic and analytical knowledge bases shape our understanding of the geography of knowledge flows and their relationship to clusters? One obvious interpretation would be to argue that localized learning and knowledge flows are more important in synthetic-knowledge industries because of the central role of tacit knowledge and F2F interaction with customers and suppliers. Indeed, many of the examples from the work of Lundvall (1988) and Von Hippel (1988) originate in sectors such as mechanical engineering and specialized industrial machinery, where learning by interacting between users and producers represents the primary mode of innovation.

By the same token, in those sectors for which analytical knowledge is more important, the greater prominence of codified and codifiable knowledge in the innovation process leads us to expect that knowledge flows and learning relationships would not be locally bound to the same extent. It should not be surprising, therefore, that the original inspiration for the 'pipeline' concept comes from the biotechnology industry (Bathelt et al. 2004; Owen-Smith and Powell 2004). Moreover, in their analysis of the Medicon Valley biotech cluster (in the Öresund region spanning eastern Denmark and southern Sweden), Coenen et al. (2004) provide at least preliminary evidence that non-local knowledge flows, as measured by co-authorship of scientific papers, are strong. Local scientific personnel collaborate actively with colleagues in Germany, the UK, and the US, with roughly one-third of local firms collaborating with partners outside Europe (Coenen et al. 2004, 1013).

However, this binary synthetic (tacit) = local, analytical (codified) = global framework is likely to be too simple to capture the complex geography of

knowledge flows. Asheim and Gertler (2005) note that, contrary to the above prediction, there is compelling evidence that analytically oriented sectors like biotech in fact exhibit strong clustering tendencies in which at least some forms of knowledge flow are locally bound. They cite the recent literature on knowledge spillovers (see Feldman 2000), in which it has been demonstrated that patent citations exhibit a strongly localized geography. They also review the 'star scientist' work of Zucker and Darby (1996), which emphasizes the commercial benefits of close relationships between biotech start-ups and highly productive or highly cited scholars in the same region. Their conclusion is that, despite the codifiability of much scientific knowledge in sectors like biotechnology, there are still some significant advantages to being physically proximate to sources of new knowledge (including knowledge of successful as well as unsuccessful experiments).

These dynamics may explain the rather striking geographical concentration of entrepreneurial activity in biotechnology as revealed in Cortright and Mayer's (2002) landmark study of US metropolitan regions. They also help us make sense of another finding from the Medicon Valley study. Notwithstanding their other findings cited above, Coenen et al. (2004) concede that intra-regional co-authorship activity between local firms and public research organizations (particularly on the Swedish side of the Öresund) remains strong.

In sum, the emerging picture seems more or less consistent with the 'buzz and pipelines' geography outlined earlier: while global research partnerships and knowledge exchanges are commonplace, these complement (rather than substitute for) strongly localized learning dynamics. Moreover, the two ends of the global pipeline are likely to be active concentrations of research activity, where buzz is rampant. However, it is worth pointing out that customers seem somewhat removed from this picture: the international collaborations described in this literature are largely supply-side in nature, linking individual researchers into non-local epistemic communities (Coenen et al. 2004).

Cluster evolution in Canada

To resolve some of these questions empirically, we have directed a large national study of cluster development that documents the emergence and evolution of local clusters in different regions of Canada.[1] The goal of our project is to determine the prevalence and success of local industrial clusters across Canada's diverse regional economies, and to analyse how the formation and growth of these clusters contributes to local economic growth and innovative capacity. Underlying this objective is a set of more substantive questions. How do local assets and relationships between economic actors enable firms – in any industry – become more innovative? Under what circumstances does 'the local' matter, and how important are local sources of knowledge and locally generated institutions (public and private) in strengthening the innovative capabilities of firms and industries? What is the relative importance of *non-local* actors, relationships, and flows of knowledge in shaping the development trajectories of localized

innovation and growth? In contrast to much of the existing international literature on clusters, we do not assume *a priori* that local relationships and flows trump non-local forms of economic interaction.

The project combines both quantitative and qualitative methodologies to study 26 cases across Canada. Each case has been examined using a common research methodology, based primarily on interviews with key cluster participants, though supplemented by statistical analysis at the regional and national level (Gertler and Levitte 2003; Amara et al. 2003). Our methodology allows for systematic comparisons between the case studies, which – again, in contrast to most of the existing work in this field – include metropolitan and non-metropolitan locations, as well as more and less knowledge-intensive industries. The selection of industries covered reflects the breadth and structure of the Canadian economy, resisting the temptation to focus solely on a narrow list of 'new economy' cases. The cases range from highly knowledge-intensive activities such as biotechnology, photonics and wireless equipment, telecommunication equipment and aerospace, to more traditional sectors such as steel, automotive parts, specialty food and beverages, and wood products. Our study also overcomes the tendency in previous policy work to rely on cluster models imported from other countries that may not reflect the Canadian reality. Our intention is to inform cluster-based policy prescriptions that are appropriate for the distinctive circumstances confronting Canada's regional economies.

The major intellectual contributions from this project are now becoming clear. Concerning the relationship between local and global forces in the development of clusters, as noted earlier, some of the most widely cited literature in the field maintains that a strong local market and strong local competition are two essential elements for the development of internationally competitive clusters. In contrast, our findings indicate that, in many successful clusters, the markets served are continental or international, that local customers constitute a relatively small proportion of the firm's total market, and that firms' most sophisticated and demanding markets are not local.

Perhaps the most vivid examples come from the life sciences, where firms in Canada's leading biotech clusters (such as Montreal, Toronto, Vancouver, and Saskatoon) have strong non-local backward and forward linkages. Recent analysis of Statistics Canada's national survey of biotechnology firms (Gertler and Levitte 2003) reveals the complex, dual geography of relationships in which successful firms are embedded. On the one hand, they tap into global knowledge markets by hiring highly qualified personnel from abroad. They also take advantage of other global flows of knowledge, through the use of scientific publications and databases, by licensing their intellectual property to foreign partners, or by licensing the intellectual property of foreign firms for their own use. When they develop collaborative relations with other firms, for both research and marketing purposes, these are both local and global in nature. On the other hand, they rely heavily on local sources of investment capital from private sources (angel investors, family and friends), and are highly likely to have spun off from another local company or research institution at some point in their past.

Similarly, there is a strong emphasis within the international cluster literature on the importance of a strong local supply base. Once again, our research has produced novel results. While certain key inputs are predominantly local (see below), relatively few regions can rely exclusively on their local knowledge base to develop, design, and produce innovative products. Conversely, knowledge flows in synthetically oriented sectors like aerospace that increasingly involve the integration of complex technology subsystems draw upon a global network of system integrators to assemble the final product. According to Niosi and Zhegu (2005, p. 22):

> Four characteristics appear when these knowledge flows are examined. First, they are mostly international. Second, they are mostly constituted of explicit and codified knowledge. Third, they involve several independent companies. And finally, they are closely tied to markets for parts, components and subassemblies.

Equally surprisingly, we find comparable results from most of our case studies of ICT clusters as well. What is readily apparent from talking to firms in the ICT clusters, however, is that the amount of inter-firm collaboration in the form of key customer or supplier relationships is relatively low. For the vast majority of firms, the focus of most economic activity – key customers, sources of supply, competitors, and important strategic partnerships – occurs at the global level. Some firms in individual clusters rely upon a local supply base for key inputs, but the vast majority tends to draw components and knowledge inputs from a diverse array of geographic sources. Thus, a core theme that emerges strongly in the study of inter-firm dynamics is the fluid nature of relations between customers, suppliers, and competitors in the cluster. Variation in types of relationships is reflected in many different combinations and permutations of inter-firm dynamics, which are rendered more complex by virtue of the fact that they occur at local or regional, national, global, and 'virtual' levels. Consequently, it would seem that explanations of ICT cluster dynamics that privilege inter-firm relationships based on proximity to each other do not capture the whole story. As is true for our biotech case studies, firms in the ICT clusters draw upon a diverse array of sources for their products (Bramwell et al. 2005).

Towards a knowledge-based typology of clusters

Can we use any of the conceptual arguments presented earlier to classify our findings into some form of typology? The principal challenge in developing any typology is to select the key categories for organizing the typology along both the horizontal and vertical axes. The proposed typology organizes cases along two key dimensions, knowledge dynamics on the one hand, and the geography of knowledge flows on the other.

The categories arranged along the knowledge-base dimension build on the typology of knowledge bases introduced earlier (based on Asheim and Gertler

2005). To the two original categories of knowledge base – analytical and synthetic – we add a third 'hybrid' to reflect those industries that draw significantly from both synthetic and analytical knowledge bases. Within the Canadian economy, these hybrid sectors might include industries, such as winemaking, specialty food products, or wood products, which have a strong link to an agricultural or natural resource base. While the generation of new product and process innovations may depend to a large extent on analytical, lab-based scientific methods that draw from a codified international body of science, their successful production also relies on craft-based know-how and tacit knowledge. While production may not be driven by the solution of customers' specific problems, there is nevertheless a strong element of niche-based differentiation. Also belonging to this category would be sectors such as medical technologies and aerospace. In both cases, while codified science and engineering knowledge make major contributions to product innovation, so too do the solution of particular customer problems and demands.

The categories for the geography of knowledge flows reflect three situations – one in which sources of knowledge are primarily local, another where global sources dominate, and a third in which firms draw significantly from both global and local sources of knowledge. Combining these two dimensions together produces the three-by-three typology in Table 11.1, which shows the classification for a selection (one-half) of our 26 cases.

Table 11.1 Typology of knowledge bases and flows

Knowledge Base	*Geography of knowledge flows*		
	Strong global sources	*Global and local sources*	*Strong local sources*
Synthetic		Ontario steel	Sudbury mining S&S[1]
			Windsor auto parts/TDM[2]
Hybrid	Montreal aerospace	Okanagan (BC) wine	Toronto medical technologies
		Niagara (Ont) wine	
		Toronto specialty food	
Analytical	Saskatoon agri-biotech	Montreal, Toronto, Vancouver biotech	
		Ottawa telecom/ photonics	

Notes
1 Supply and services
2 Tool, die and mould

From the distribution of entries in this matrix, several important insights emerge. First, while there is a tendency for synthetic-knowledge industries to source their knowledge locally, this is not universally true. In the case of Ontario steel, firms such as Dofasco in Hamilton are embedded in both local and international knowledge networks. Second, while cases such as agricultural biotech in Saskatoon support the predicted correspondence between analytical knowledge and global sourcing, other analytical-knowledge cases such as biotech in Montreal, Toronto, and Vancouver, or telecom equipment and photonics in Ottawa, depend on a mix of strong local and global knowledge sources and flows. Third, hybrid sectors show no clear tendency toward one scale or the other. Cases such as Toronto's medical technologies industry – for which analytical knowledge is a strong complement to synthetic forms of knowledge – show strong dependence on local knowledge sources. Food and wine clusters in Toronto, Niagara, and Okanagan rely significantly on both scales of knowledge flow, while Montreal aerospace draws very little unique knowledge from local sources.

While these results defy easy generalization, they certainly demonstrate the limits to claims by Porter and others concerning the predominance of local knowledge flows.

What remains of the local?

Notwithstanding the complex, multi-scalar geography of knowledge described above, certain characteristics and properties of local industrial clusters remain critically important to the competitive success of firms in a wide range of industries. Despite the importance of non-local markets, knowledge flows, and (in some cases) supply bases, our research confirms that the local dynamics of social interaction between members of the cluster are crucial. These intra-cluster relationships promote the local circulation of knowledge, underpinning the learning processes that enable firms to succeed at innovation (a finding that would appear to support the arguments in Malmberg and Power 2005b). Our work documents the nature and significance of these knowledge flows, and the various forms they take. The local participants in these social learning systems include firms, institutions of education and research, venture capitalists, producer associations and specialized government research labs. In this way, the case studies document a balance between local and non-local relationships and knowledge flows – in other words the dynamic tension between the local 'buzz' described above and global 'pipelines' that circulate knowledge between clusters.

Furthermore, the case studies suggest that the most successful clusters have profited from the development of strong social networks at the community level and the emergence of dedicated, community-based organizations. These entities link leaders in the individual clusters to a broader cross-section of the community. They appear to be supported by new institutions of civic governance that identify problems impeding the growth of the cluster and help mobilize support across the community for proposed solutions. We have found some

evidence to suggest that size is a critical variable in the success of civic engagement, with some of the larger urban centres encountering greater difficulty in achieving effective degrees of mobilization.

Another finding of fundamental importance, relating to the role of local assets in the innovation process, concerns the relationship between knowledge infrastructure and cluster emergence and evolution. The international literature on the most celebrated clusters identifies research infrastructure, especially post-secondary educational institutions, as the essential ingredient for cluster formation (Gibbons 2000, Kenney and Patton forthcoming). Significantly, and to the contrary, our research indicates that, with a few notable exceptions, local research infrastructure (as a key part of the regional innovation system) plays a *supporting, not a causal*, role in the growth of clusters in Canada. In some significant instances, the local development of advanced educational and research programs clearly *follows* the emergence of a dynamic local cluster, rather than preceding it. In most cases, the presence of a strong research infrastructure constitutes a local antecedent that lays the groundwork for the emergence of a cluster. This research infrastructure also contributes to the presence of a 'thick' labour market in the local economy, which serves as a magnet for firms in search of highly skilled labour. It may also attract firms to a city-region in the expectation of tapping into the knowledge base that exists. However, strong research infrastructure and a thick labour market are underlying conditions that extend beyond the boundaries of individual clusters.

One of the most consistent findings from our work concerns the role of local labour markets and talent. If there is one type of input that is overwhelmingly local, it is highly skilled labour. It is clear that the depth and breadth of the local labour market is the key ingredient defining a cluster's ability to support knowledge-intensive production. It is also the factor that is most amenable to public policy influence. However, our work suggests that the creation of a talented labour pool in turn depends on many different factors, including not only the strength of local post-secondary education and specialized training institutions but also a set of 'quality of place' characteristics that determine a region's ability to retain well-educated labour and attract it from elsewhere (Gertler and Vinodrai 2005). However, this finding has also revealed a potential downside to the talent factor: not all locations in the country will be equally successful in the pursuit of this objective. Some of our cases have encountered significant obstacles in developing a deep labour market, despite persistent efforts.

The results presented in this chapter, based on our national study of cluster development in Canada's regions, suggest that many of the taken-for-granted qualities of clusters – and especially the geography of knowledge flows supporting innovation – may not obtain in reality. Clearly, this does not mean necessarily that 'the local' is unimportant. Rather, it becomes important for different reasons, relating to social interaction, leadership dynamics, and labour markets. Nevertheless, the risk of implementing ill-conceived policy initiatives is great so long as public agencies labour under misguided notions concerning the local self-sufficiency of 'successful' clusters.

Notes

1 See http://www.utoronto.ca/isrn for a full project description and publications arising from this work. This project, funded by the Social Science and Humanities Research Council of Canada, has run from 2001 to 2005. For the most recent collection of case studies emerging from this project, see Wolfe and Lucas (2005).

References

Amara, N., Landry, R. and Ouimet, M. 2003. Milieux innovateurs: determinants and policy implications. Paper presented at the DRUID Summer Conference, Elsinore, Denmark, June 12–14. (available at http://www.druid.dk/conferences/summer 2003/Papers/AMARA_LANDRY_OUIMET.pdf).

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

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

Bramwell, A., Nelles, J. and Wolfe, D. 2005. Knowledge, innovation and institutions: Global and local dimensions of the ICT cluster in Waterloo, Canada. Paper presented at the DRUID Academy Winter Conference, Jan. 27–9 (available at http://www.druid.dk/ocs/viewpaper.php?id=347&cf=2).

Breschi, S. and Malerba, F. 2001. The geography of innovation and economic clustering: Some introductory notes, *Industrial and Corporate Change*, 10:4, 817–33.

Brown, J.S. and Duguid, P. 2000. Mysteries of the region: Knowledge dynamics in Silicon Valley, in C.-M. Lee, W.F. Miller, M.G. Hancock and H.S. Rowen (eds) *The Silicon Valley Edge*. Stanford: Stanford University Press, pp. 16–39.

Coenen, L, Moodysson, J. and Asheim, B.T. 2004. Nodes, networks and proximities: On the knowledge dynamics of the Medicon Valley biotech cluster, *European Planning Studies*, 12:7, 1003–18.

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

Davies, H. and Ellis, P. 2000. Porter's *Competitive Advantage of Nations*: time for the final judgement? *Journal of Management Studies*, 37:8, 1189–213.

Feldman, M.P. 2000. Location and innovation: The new economic geography of innovation, spillovers, and agglomeration, in G.L. Clark, M.P. Feldman, and M.S. Gertler (eds) *The Oxford Handbook of Economic Geography*, Oxford: Oxford University Press, pp. 373–94.

Feldman, M.P., Francis, J. and Bercovitz, J. 2005. Creating a cluster while building a firm: Entrepreneurs and the formation of industrial clusters, *Regional Studies*, 39:1, 129–41.

Gertler, M.S. 1995. 'Being there': Proximity, organization, and culture in the development and adoption of advanced manufacturing technologies, *Economic Geography*, 71, 1–26.

Gertler, M.S. 2003. The undefinable tacitness of being (there): Tacit knowledge and the economic geography of context, *Journal of Economic Geography*, 3, 75–99.

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

Gertler, M.S. and Levitte, Y.M. 2003. Local nodes in global networks: The geography of knowledge flows in biotechnology innovation. Paper presented at the DRUID Summer Conference, Elsinore, Denmark, June 12–14 (available at http://www.druid.dk/conferences/summer2003/Papers/GERTLER_LEVITTE.pdf).

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

Gibbons, J.F. (2000) The role of Stanford University: A dean's reflections, in C.-M. Lee, W.F. Miller, M.G. Hancock, and H.S. Rowen (eds) *The Silicon Valley Edge*. Stanford: Stanford University Press, pp. 200–17.

Hendry, C., Brown, J. and Defillippi, R. 2000. Regional clustering of high-technology based firms: Opto-electronics in three countries, *Regional Studies*, 34:2, 129–44.

Johnson, B., Lorenz, E. and Lundvall, B-Å. 2002. Why all this fuss about codified and tacit knowledge? *Industrial and Corporate Change*, 11, 245–62.

Kash, D.E. and Rycroft, R.W. 2000. Patterns of innovating complex technologies: A framework for adaptive network strategies, *Research Policy*, 29, 819–31.

Kenney, M. and Patton, D. forthcoming. The co-evolution of technologies and institutions: Silicon Valley as the ideal-typical high technology cluster, in P. Braunerhjelm and M.P. Feldman (eds) *Cluster Genesis: The Emergence of Technology Clusters and the Implication for Government Policy*. Oxford: Oxford University Press.

Laestadius, S. 1998. Technology level, knowledge formation and industrial competence in paper manufacturing, in G. Eliasson et al. (eds) *Microfoundations of Economic Growth: A Schumpeterian Perspective*. Ann Arbor: University of Michigan Press, pp. 212–26.

Lundvall, B-Å. 1988. Innovation as an interactive process: From user-producer interaction to the national system of innovation, in G. Dosi, C. Freeman, G. Silverberg and L. Soete (eds) *Technical Change and Economic Theory*. London: Pinter, pp. 349–69.

Malerba, F. 2005. Sectoral systems: How and why innovation differs across sectors, in J. Fagerberg, D. Mowery and R. Nelson (eds) *The Oxford Handbook of Innovation*. Oxford: Oxford University Press.

Malmberg, A. and Maskell, P. 2002. The elusive concept of localization economies: Towards a knowledge-based theory of spatial clustering, *Environment & Planning A*, 34, 429–49.

Malmberg, A. and Power, D. 2003. (How) do (firms in) clusters create knowledge? Paper presented at the DRUID Summer Conference, Elsinore, Denmark, June 12–14. (available at http://www.druid.dk/conferences/summer2003/Papers/MALMBERG_POWER.pdf).

Malmberg, A. and Power, D. 2005a. On the role of global demand in local innovation processes, in P. Shapira and G. Fuchs (eds) *Rethinking Regional Innovation and Change: Path Dependency or Regional Breakthrough?* Amsterdam: Kluwer Academic Publishers.

Malmberg, A. and Power, D. 2005b. True clusters: A severe case of conceptual headache, in B.T. Asheim, P. Cooke, and R.L. Martin (eds) *Clusters and Regional Development*. London: Routledge (forthcoming).

Martin, R. and Sunley, P. (2003) Deconstructing clusters: Chaotic concept or policy panacea, *Journal of Economic Geography*, 3:1, 5–35.

Maskell, P. 2001. Towards a knowledge-based theory of the geographic cluster, *Industrial and Corporate Change*, 10:4, 921–43.

Niosi, J. and Zhegu, M. 2005. Aerospace clusters: Local or global knowledge spillovers, *Industry and Innovation*, 12:1, 5–29.

Nonaka, I. and Takeuchi, H. 1995. *The Knowledge Creating Company*. Oxford: Oxford University Press.

Nonaka, I., Toyama, R. and Nagata, A. 2000. A firm as a knowledge-creating entity: A new perspective on the theory of the firm, *Industrial and Corporate Change*, 9:1, 1–20.

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

Pavitt, K. 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory, *Research Policy*, 13, 343–73.

Porter, M.E. 2000. Locations, clusters, and company strategy, in G.L. Clark, M.P. Feldman and M.S. Gertler (eds) *The Oxford Handbook of Economic Geography*. Oxford: Oxford University Press, pp. 253–74.

Saxenian, A. 1994. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Cambridge, MA: Harvard University Press.

Storper, M. and Leamer, E.E. 2001. The economic geography of the internet age, *Journal of International Business Studies*, 32, 641–65.

Storper, M. and Venables, A.J. 2004. Buzz: Face-to-face contact and the urban economy, *Journal of Economic Geography* 4:4, 351–70.

Sturgeon, T.J. 2003. What really goes on in Silicon Valley? Spatial clustering and dispersal in modular production networks, *Journal of Economic Geography*, 3, 199–225.

Von Hippel, E. 1988. *The Sources of Innovation*. Oxford: Oxford University Press.

Wolfe, D.A. 2005. Innovation and research funding: The role of government support, in F. Iacobucci and C. Tuohy (eds) *Taking Public Universities Seriously*. Toronto: University of Toronto Press, pp. 316–40.

Wolfe, D.A. and Gertler, M.S. 2004. Clusters from the inside and out: Insights from the Canadian study of cluster development, *Urban Studies*, 41:5/6, 1071–93.

Wolfe, D.A. and Lucas, M. (eds) 2005. *Global Networks and Local Linkages: The Paradox of Cluster Development in an Open Economy*. Montreal and Kingston: McGill-Queen's University Press and Queen's School of Policy Studies.

Zucker, L.G. and Darby, M.R. 1996. Star scientists and institutional transformation: patterns of invention and innovation in the formation of the biotechnology industry, *Proceedings of the National Academy of Science*, 93, 12709–16.

Acknowledgement The authors gratefully acknowledge the Social Sciences and Humanities Research Council of Canada for supporting this research through its Major Collaborative Research Initiatives Program