Complexity in Cluster Development:
Towards an Evolutionary Theory to Guide Policy Development

Cooper H Langford and Jeremy K Hall

Copyright of the paper belongs to the author(s). Submission of a paper grants permission to the Triple Helix 9 Scientific Committee to include it in the conference material and to place it on relevant websites. The Scientific Committee may invite papers accepted for the conference to be considered for publication in Special Issues of selected journals.

Key words: evolutionary complexity, cluster, imitation, NK theory, analogy

Theme 1.9

The role of technological clusters in regional development has drawn widespread attention from academics, policy-makers and managers because clusters may stimulate innovative behavior, leading to industrial competitiveness and economic growth (Arthur, 1990; Krugman, 1991; Porter, 1990; Furman et al, 2002). Since Marshall (1947), it has been recognized that specific industries become central to the industrial systems of certain regions, and that policies might be developed to improve the economic development climate (Porter, 1990; Furman et al, 2002). Among other benefits, agglomeration economies may stimulate trust through common conventions, norms and flows of tacit and codified knowledge (Audretsch, 1998; Storper and Leamer, 2001; Storper and Venables; 2004). A systemic approach to clustering is useful in understanding how innovation affects firm competitiveness and how collective factors affect managerial options (Porter 1990, Lundvall 1988; von Hippel, 1988; Gertler 1995; Pavitt, 1984; Van de Ven, 1986).

However, scholars such as Cook (2005), Florida (2002), Martin and Sunley (2003), Garnsey (1998) and Storper (1995) have been critical of the cluster concept, arguing that it is overly simplistic, with causal factors difficult to identify and results which cannot be evaluated. These authors also argue that attempts to identify essential components in one successful cluster and apply them elsewhere usually fail. In this paper we argue that ‘cheap and easy’ cluster policy approaches (Martin & Sunley, 2003) that use simple imitation of successful regions does not address crucial path dependent idiosyncrasies and the generally complex nature of inter-organizational relationships and innovation dynamics. Yet we recognize the power of analogy (Gavetti et al, 2005) and that analysis of experience elsewhere enters all rational policy making.

Drawing on institutional theory (DiMaggio and Powell, 1983) and complexity theory (Gavetti et al, 2005; Kauffman; 1993), we attempt to explain the limitations of contemporary cluster thinking, specifically the difficulties and futility of simple imitation of features of existing clusters. The impact of clustering on firm competitiveness and regional advantage is not simple; managers and policy-makers must recognize the dynamic, path dependent and evolutionary nature of regional specialization and innovativeness, as well as the interdependencies among key actors. Rather than a reductionist analysis of its elementary components (Laughlin, 2005), we suggest that the cluster should be regarded as an *emergent phenomenon.* Under evolutionary and complex circumstances, Gavetti et al (2005) suggest that analogical reasoning, the ability to transfer useful wisdom from a range of previous similar settings, followed by incremental local search is appropriate, and we attempt a theoretical foundation for the use of analogy in the context of clusters through complexity theory.

After an overview of the clusters literature, followed by an analysis of clusters as an institutional process and emergent evolutionary phenomena. We discuss three cases, all with similar geographic settings and similarly transformative technology that requires access to global knowledge systems. Drawing on data from the cases, we present a formal model and analysis based on Kauffman's N,K theory as extended for analysis of analogy by Gavetti et al (2005). Despite the similarities regarding their global knowledge networks and common geographic features, we present an analysis implying that the three clusters evolved on significantly distinctive paths. The result of our evolutionary analysis supports a more subtle model of advantage as an input for policy analysis, and provides enhanced alertness (Kirzner, 1973) and awareness (Langer (1989; Weick, 1996) for managers and entrepreneurs seeking advantage. We conclude with the policy and managerial implications.

AN OVERVIEW AND CRITIQUE OF CLUSTER STUDIES

The cluster concept arises from several considerations and disciplines. Regional concentration of an industry may stimulate innovation, competitiveness and economic growth, where economies of agglomeration (i.e. being in a location with similar firms and appropriate infrastructure) may create net benefits for individual firms and the region (Arthur, 1990; Krugman, 1991), as well as contribute towards national innovative capacity (Furman et al, 2002). Indeed, cluster analysis started from efforts to identify specific elements of regional advantage as a means of understanding national economic competitiveness (Porter, 1990; 1998)

The technical and resource base may attract new firms, or create spin-offs in the region (Melecki, 1985). Common conventions and norms, and locally available knowledge regarding reliability and trustworthiness further support local knowledge flows, both tacit and codified (Audretsch, 1998; Storper and Leamer, 2001; Storper and Venables; 2004). Clusters may also facilitate collaborative and competitive interactions with local customers and suppliers, through which learning generates mutual benefits for users and producers (Porter 1990, Lundvall 1988; von Hippel, 1988; Gertler 1995; Silvestre and Dalcol, 2009). The impact of technology policy and related industrial polices cannot be fully understood without understanding regional aspects (Padmore and Gibson, 1998), nor can innovativeness be understood without understanding the firm's industrial context (Pavitt, 1984; Van de Ven, 1986). Fundamentally, innovation does not occur in isolation (Richardson, 1972; Schumpeter, 1942; Nelson & Winter, 1977; 1982), and innovation predominantly happens through interactions among various actors (von Hippel, 1998, Lundvall, 1988) rather than resulting from "the creative act of the solitary genius" (Malberg & Power, 2005: 410).

Others, including Florida (2002) and Martin & Sunley, (2003), have been critical of the cluster concept and its policy use, arguing that its formulations are conceptually and methodologically weak. In their view, a cluster policy may be no more than a relatively simplistic regional development policy tool that provides easily interpreted recipes and actionable checklists. Martin & Sunley (2003) further argue that cluster analysis has been lucrative for consultancies and academics ('an academic and policy fashion item'), and is a relatively 'cheap and easy' policy approach, accomplished by a 'six-week study' that generally cannot be disproved (the non-falsifiability problem). However, the central premise, recognized since Marshall (1947), is that particular regions concentrate activity and innovation in specific industries locally, and that activity in an industry is distributed heterogeneously. Arguably, the main drawback to ‘cheap and easy’ cluster policy is that it uses simple imitation of successful regions rather than deeper analysis of the opportunities for advantage specific to a particular region. Florida (2002) described simplistic imitation of, especially ‘Silicon Valley’, as producing a ‘silicon nowhere’. Such policy insufficiently addresses path dependent idiosyncrasies and the generally complex nature of inter-organizational relationships and innovation dynamics.

At this point we do not select one particular cluster definition from the cited references but rather adopt an empirical perspective: successful concentration of an innovative industry in a region accompanied by demonstrable interactions can provide an operational working definition. We acknowledge that reasons for such success remain elusive (Garnsey, 1998) and we will address these concerns later. In reality, strategies commonly employed do not replicate the successes of the prototype Silicon Valley cluster (Florida, 2002; Storper, 1995). Neither does application of models always produce the desired innovative outcome (Garnsey, 1998). Institutional isomorphism (DiMaggio and Powell, 1983) and imitative strategies (Cyert & March, 1963; Freeman and Soete, 1997) are unlikely to further innovative behavior, by firms within a cluster (Pouder and St. John, 1996), or reward policy-makers attempting to build and nourish a cluster. A cluster policy may present an innovation paradox – at the firm level promising a dynamic and innovative environment on the one hand, and encouraging conformity and isomorphism on the other. Agency problems (Jensen & Meckling, 1976) may also emerge, as policy makers seen as acting on regional industrial development face difficulties in assessing the outcomes of their efforts. Failure to recognize the dynamic, path dependent and evolutionary nature of regional specialization and innovativeness is likely to miss crucial interdependencies among local actors support firm competitiveness and cluster success or failure.

If a cluster is seen as an *emergent phenomenon* not readily predicted from a reductionist analysis of its elementary components (Laughlin, 2005), an evolutionary analysis would aim to provide a clearer model of advantage. It should suggest adoption of an open multi-dimensional approach. Drawing on an evolutionary simulation model, Gavetti et al (2005) argue that in the face of complex decision-making, flexibly adapted analogical reasoning is an appropriate heuristic, and that satisfactory options should override optimization strategies.

CLUSTERS AS AN INSTITUTIONAL PROCESS

The promises - and problems – of cluster theory can be framed within the context of institutional theory (Hakanson, 2005; Pouder and St. John, 1996; Steinle & Schiele, 2002). Institutionalization is an evolutionary process that involves the emergence of new practices, rules and technologies that later diffuse, become legitimate at varying rates and eventually accepted within a field (Leblebici, Salancik, Copay, & King, 1991; Meyer & Rowan, 1977). Early adopters typically base their decisions on technical grounds, whereas later adopters respond primarily to legitimacy pressures (Tolbert & Zucker, 1983), and typically follow an S-curve diffusion path (Rogers, 1995). Once established, firms endure with greater or lesser degrees of stability (Christensen, 1997; Fligstein, 1991). Arguably the cluster concept has become legitimized and accepted, as evidenced by the widespread research interest and application by policy makers. However, there remains considerable debate over concrete advantages versus a 'herd mentality' (Langford et al, 2006) or 'fools rush in' (Aldrich and Fiol, 1994) explanation for the popularity of the cluster concept.

DiMaggio and Powell (1983) argue that there are three institutionalization pressures: coercive, normative, and mimetic. Coercive pressure refers to the threat or use of force by a powerful actor in order to gain compliance. Normative pressure arises from cultural and professional expectations that actors feel compelled to honor. Mimetic pressure arises as a response to the perception that imitation of successful referent actors may provide success. Mimetic pressures appear to be the cause of much cluster interest, where policy-makers are under pressure to replicate the widely popularized successes of one region to their own. Firms have an incentive to cluster to enhance legitimacy and avoid liabilities of newness (Aldrich & Fiol, 1994; Pouder and St John, 1996), while the participation in inter-firm relationships within the cluster can also enhance legitimacy, which in turn can be a source of encouragement for companies to join a cluster and remain in it over time (Scott, 1989). Once firms begin to concentrate in an area, they acquire agglomeration economies and legitimacy furthers cluster growth, at the expense of non-clustered firms. For example, Steinle and Schiele (2002) cite Fabiani and

Pelligrini's (1998) study (published in Italian), which found that isolated companies suffer from a 'periphery discount' amounting to 40% lower returns.

The initial success of Silicon Valley discussed by Saxenian (1994) is an example of an early adopter cluster, with its success providing legitimacy and pressure for mimetic behavior for other jurisdictions. Note however that the dynamics of institutionalization form a heterogeneous set of processes that are temporally and context specific (Lawrence et al, 2001), as is the diffusion of innovation (Hoffman, 1999; Leblebici et al., 1991; Rogers, 1995; Tushman & Anderson, 1986). While mimetic pressures may be strong, the evolutionary, path dependent and idiosyncratic nature of innovation and institutional dynamics makes simple imitative strategies futile, particularly because clusters involve many dimensions of complexity.

CLUSTERS AS EMERGENT EVOLUTIONARY PHENOMENA

The starting point for a formal evolutionary model is based on the proposition that all classes of problem solving, including development of intentional social structures, can be usefully regarded as design problems (Simon, 1969). The fundamental insight on design is Simon's (1969, p. 36) recognition of *bounded rationality*. In complex contexts, it is not realistic to seek optimal solutions. For reasons of either limits on time and resources or limits on required information because of high degrees of uncertainty (commonly both), the best available goal is a satisfactory solution with an unknown relationship to a hypothetical optimum (Simon's called 'satisficing'). For cluster evolution, coordination of the diverse elements further complicates design (Wolter, 2005). We try to capture the basis of structural constraints that operate on a satisficing search for success in a set of specific regional industrial systems, especially those constraints that are responsible for making favorable outcomes differ in highly significant ways so that distinct forms of success emerge.

Garnsey (1998) and Wolter (2005) have explicitly (others implicitly) recognized the promise of complexity analysis for unpacking the cluster concept. Pouder and St. John (1996) discuss cluster dynamics from an evolutionary perspective, suggesting: "Researchers of system dynamics using mathematical analysis … could explore differences between some of the variables used to compare hot spots [clusters] and outside industry competitors". Van de Ven & Poole, (1995) argue that nonlinear models and chaotic processes may offer better explanations of dynamic relationships.

Evolutionary study of cluster characteristics invites an analysis as complex evolving systems formalized according to Kauffman's (1993) theory. The next sections develop a conceptual and formal structure showing tests for diverse paths to *emergent success* among several clusters that share a common base in transformative technologies exploiting a global R&D system. A preliminary analysis of three reported cases with a common Western Canadian setting illustrates how distinct structures can emerge from a fundamentally similar environment. These cases is intentionally bias as much as possible for similarities in the economic geography so that the hypothesis of distinctiveness may be subjected to the most strenuous test.

N,K models (Kauffman, 1993) have been used to digitally simulate the dynamics of otherwise qualitative models of innovation at varying dimensions of complexity. Starting from relatively lower dimensions, Frenken (2001, 2006) explored product evolution in aircraft and motorcycles. At the next level, formal **N**,**K** simulations have been used to explore firm strategy, examining limitations of "best practices" imitation (Rivkin, 2000), and most elaborately the use of strategic analogy (Gavetti et al, 2005). Choi et al (2001) added a dimension of complexity by treating supply networks as complex adaptive systems, with trade-offs between lower transaction costs and supplier responsiveness versus higher supplier risk and innovation. At yet another dimension, numerical simulation models of the co-ordination and decentralization aspects of clusters were treated in an **N,K** framework by Wolter (2005).

This paper relies on, but departs from, these studies in applying a formal evolutionary analysis to a relatively high dimension of complexity (technological clusters) using *empirical data* rather than numerical modeling. Due to our use of empirical data, we can relax some assumptions imposed in simulation models for computational purposes. The empirical data comes from studies (Langford et al. 2003, 2005) of the evolution of three specific Western Canadian clusters active in global industries: wireless telecommunication (Calgary and Vancouver) and global positioning systems (GPS) (Calgary). We attempt two objectives through empirical **N,K** analysis:

1. demonstrate how diversity of success can emerge despite a largely common basic environment, and go beyond simulation to illustrate empirical applicability of **N,K** models to case studies through identification of enough matrix elements to exhibit emerging diversity

2. From this base, revisit the concept of a cluster policy by drawing attention to the deficiencies of imitative approaches, and then suggest policy approaches based on fruitful uses of analogy that are consistent with the evolutionary perspective.

Quantitative Data

Qualitative information below was supplemented in the three relevant cases by surveys conducted on the wireless industry in Alberta by KPMG for WiTec Alberta, the industry association, (KPMG, 2005) and on wireless in BC by PricewaterhouseCoopers for the trade association, The Wireless Innovation Network of BC (WINBC), (PwC, 2005). The Alberta survey had 86 respondents in December 2004, mainly CEOs or Presidents. There are about 300 companies (the majority in the Calgary metropolitan area) in the industry with revenue of $3.5 billion and approximately 16,000 employees (KPMG, 2005). Fifty-nine percent of the companies were less than 5 years old and 33% over 10 years old. Sixty-seven percent of the respondents were profitable in 2004. Eighty-four percent expect to expand their workforce in the next two years. Thirty-one percent of the firms spent more than 20% of revenue on R&D, while 33% spent between one and five percent on formal R&D. Fifty-three percent expected to increase R&D spending in the next five years, 63% of those by more than 25%. Company cash flow was the main source of capital (70%). Public equity markets and venture capital, minor in the past, were expected to play a larger future role.

The critical success factors identified were technology development, sales execution, recruitment of skilled labor, access to target markets, and R&D capacity. Barriers to growth included funding, attracting qualified employees, and developing new markets. 'New products' or technology was identified as the major growth vehicle, confirming the commitment to innovation.

The BC survey had 91 respondents in April-May 2005 from 216 requests to reply to an on-line survey. For the sector (81% located in the Vancouver area), aggregate revenue was estimated at $649 million, not including wireless service operators. Employment was reported at 5,153, representing 39% growth since 2002. Companies identified sources of funding as follows: cash flow (60%), founders and proprietors (50%), government (25%), friends and family (21%). Seventy four percent of the respondents indicated they would seek funding in the next two years with an aggregate goal of $127 million. The companies were young, with 50% started between 1999 and 2003. However, veterans of earlier activity led a number of newcomers. Drivers of growth identified were new products or technology, new industry partnerships, and new qualified employees. Critical success factors included sales execution and access to target markets. There was recognition of the strength of the cluster and 84% of the respondents believed a strong local sector was important. The companies had good relations with customers who publicly endorsed their products. Fifty three percent of the companies reported 10 or more such favorable customers. The similarities in the quantitative data strongly confirm our hypothesis that these are parallel success stories based on similar technical fundamentals, with a commitment to innovation as a major success factor. Especially, the BC survey underlines the clustering advantages. These emerged as well in Calgary from interviews.

Qualitative Data

All three of our industrial clusters are engaged in global development of transformative technologies. Innovation in the telecommunication and GPS cases is very rapid. Product life cycles are short and innovation depends on underlying supplier development of microcircuits and software. These wireless and GPS clusters report little research collaboration with local research institutions. Types of innovation reported focus on identification of system integration and products for market niches, followed by innovative business models. Patent citation analysis underlines the global nature of codified knowledge: US patents of three representative firms (large, medium, and small) from each of Calgary and Vancouver contained extensive patent citations from inventors in the US, Europe and Asia, but virtually none to their own or other local inventors. The Calgary and Vancouver patents were widely cited in the patent literature, but local citation was almost non-existent.

The three Western Canadian examples do not exhibit the local competitive relationships identified by Porter (1990) as crucial for competitive advantage. Wolfe and Gertler (2003) make the distinction between closed clusters (where all value chain members and competitors are present) versus open clusters (where non-local competition and non-local value-chain members predominate). They recognized that all clusters considered that were based on transformative technologies were open. , The firms in the wireless and GPS clusters characteristically cannot identify local competitors. Relations with suppliers are similarly non-local with the exception of services of some design firms and contract manufacturers. Both non-local competitors and, to a lesser extent, non-local suppliers, are reported to be a significant source of ideas for wireless and GPS innovation. The firms use global "pipelines" (Malmberg and Power, 2005), and global linkages dominate over local. These findings are consistent with Penrose's (1995, p. xix) observation that "…*the rapid and intricate evolution of modern technology often makes it necessary for firms … around the world to be closely in touch with developments in the research and innovation of firms in many centres*".

In both Calgary and Vancouver expert professional services such as legal and accounting, are readily available. Neither Calgary nor Vancouver has clusters reliant primarily on local capital markets, but Vancouver has the stronger local capital market for high technology.

The major advantage of location in Calgary and Vancouver identified by all interviewees was the presence of a "talent pool" or thick labour market. In both centres, this was associated with the attraction of the local quality of life. A Calgary interviewee commented: "*I hire 27 year old engineers with one an a half children and a mountain bike. I can attract them here*". The factors are a clean safe city and easy mountain access. A Vancouver comment was: "*we started this business because we were in Vancouver and wanted to stay*". Major factors are a "laid back" lifestyle favored by the mild climate, the ocean, and mountains. Both cities score well on 'creative class' metrics (Florida, 2002, Gertler et al, 2002). The role of the talent pool emphasizes the role of tacit[1] knowledge in development of local advantage. Consistent with much of the clusters literature, regionally "sticky" knowledge circulates from face-to-face contacts

[1] The term tacit is used loosely here to cover both knowledge "tacit" in Polanyi's proper sense of uncodifiable (Polanyi, 1958, Part II) and that not yet codified because of lack of sufficient motivation to accept the "price" of codification (Cowan et al, 2000).

and, especially, the migration of personnel among firm, which was not resented by senior executives interviewed.

We submit that the above evidence satisfies requirements for cases that exhibit the strong parallels in the nature of the business, the technological situation and the geopolitical environment that might most favourably recommend imitative strategies.

Four functional Areas

We now turn to how a formal evolutionary model might recognize significantly different paths of evolution of these apparently quite similar agglomerations. Especially, local factor interdependencies arising from complexity may be seen to differentiate their needs and paths of development.

Gavetti et al. (2005) begin pursuit of analogy by recognizing broad factors that may have a number of specific sub-elements associated with each. Division into broad factors grouping sub-elements implements Simon's (1968) simplification of design problems by 'partial decomposition'. The decomposition is 'partial' because some of the detailed factors will exhibit interdependency with factors belonging mainly to another broad category. For example, in designing a car we might approach designing the engine and the transmission as separate problems while recognizing that some elements of each will be dependent on elements of the other.

Based on a grounded theory approach to the interview data, we assign features to four broad 'functional areas' as a partial decomposition common to the four cases. It will allow for an analysis of the relationships within the cluster:

1. The <u>knowledge structure</u> including the role of research institutions, firm R&D strategy, relationships to global knowledge, and sources of knowledge based advantage,
2. The local <u>networking</u>, including whether it is based on formal or informal organizations and the nature of anchors of the networks,
3. The <u>talent</u> pool, including specifically the key technical/business backgrounds, key recruiting foci, and retention strategy and outcomes,

4. The infrastructure including key sources of finance (especially in early cluster development), the effect of quality of life in the region, and the availability of professional services.

Our evolutionary analysis below will be organized around these major feature categories called ‘functional areas’ (our ‘engine’, ‘transmission’, ‘braking system’ and ‘body’ modules, to pursue the car analogy) and will focus especially on how interdependencies arise among features within different functional areas in each case.

*The **N,K** Model and Cluster Dynamics*

The **N,K** model was introduced by Kauffman (1993) to describe evolutionary phenomena in biology. **N** represented the number of genetically controlled features that might adopt one of several allele values (e.g. ‘eye color’ gene with allele values ‘brown’, ‘blue’, ‘green’ ….). The fitness value (survival) of a particular combination of choices was represented by W. It was recognized that allele choices on genes do not contribute to fitness independently, and the number of other genes influencing the fitness outcome of a particular allele choice for gene $\mathbf{N}_i$ is represented by an integer, $\mathbf{K}_\mathbf{i}$, describing the number of other genes $\mathbf{N}_k$ whose allele values influence the fitness outcome of the choice for $\mathbf{N}_i$. The value of **K** characterizes the number of ‘*epistatic*’ relationships of a gene.

Kauffman (1993) recognized that this model had relevance to a wide range of evolutionary situations. Examples are organizational performance (Levinthal et al, 2002) and a firm’s search for technological improvements (Kauffman et al, 2000). As noted, it has been applied by others to product evolution (Frenken, 2001; 2006), firm development (Rivkin, 2000), analysis of strategic analogy (Gavetti et al, 2005), control of supply networks (Choi et al, 2001), the management of sustainable supply chains (Matos and Hall, 2007) and industrial cluster coordination (Wolter, 2005). Table 1 summarizes the use of a biological metaphor for various dimensions of complexity.

Once all **N,K** are specified and alleles assigned, an overall fitness, W, results. The analysis of the variation of W as a function of the parameter choices produces the “fitness landscape” for the evolving system. Success depends on evolution toward a high fitness value or “peak” in this landscape. For **K** greater than one, the landscape develops multiple local maxima (increasing in number with **K**) and becomes rugged. For even modest **K** values, the fitness landscape begins to resemble the rugged peak distribution of the Alps or the Rocky Mountains and search for an optimum must give way to "satisfacing" (Simon, 1968). Computer simulations have illuminated many of the properties of fitness landscapes. These take a number of features, **N**, and postulate a typical number of interrelationships, **K**. For simulation purposes, allele choices for a feature are modeled as binary (0 or 1).

Increasing interdependency among system elements alters the fitness landscape by increasing the difference in fitness values of system configurations differing in only a few parameters. If **K**=0, the fitness value of each element depends only on its own state. Thus, two system configurations with only one different element state would have similar fitness values (separated by the difference in fitness of that element's two states). However, if **K**>0, the fitness value of any element's state in the system is affected by the states of **K** other elements. Each element has A^{K+1} different fitness contributions with changes of element states (Kauffman, 1993, p. 239). Neighboring configurations differing by the state of one (detail level) element may differ significantly in fitness if that element has significant impact on the fitness of other element states. Rivkin (2000) examined the problems faced in adopting a successful practice from another firm. A first simulation evaluated incremental improvements where an imitator changed one feature at a time. Rivkin (2000 p.836) released 500 random imitators on 10 fitness landscapes, still allowing only incremental improvement. For **N** = 24 and **K** = 3, only 5.7% of imitators matched or exceeded the benchmark performance that supplied the imitated feature. For the not unrealistic value of **K** = 7, this fell to 1.4%. Nothing in the formalism changes if we move to the right in Table 1 and replace firms by clusters. What does change is the degree of managerial control, which is sharply reduced in a network of independent corporate entities.

Functional Areas and Detailed Characteristics of an Industry Based on Global Science

Clearly, the number of features, **N**, that are important to trace the evolution of a real example of a regional cluster in an industry based on global science must be very large. As Simon (1968) pointed out, design strategy simplifies the search process by decomposing design problems into modules that may be independently analyzed and improved. This is represented in the **N**,**K** by block diagonalization of the matrix of features and fitness so that, as far *as possible*, epistatic relationships represented by **K** connect only features in the same block (module). Returning to an automobile as an example, the attempt is to place all features of an engine design in one module and all features of transmission design in another. Still, in practice, some features of engine design affect transmission design performance and vice-versa. Generally, the decomposition of a complex system into modules will not be complete, and only a partial decomposition can be achieved (Simon, 1968). The interdependency (epistatic) relationships that connect features in different modules, those responsible for the 'partial' character of the decomposition, will *play a key role* since they will determine the overall architecture of the assembled system. In formal terms, the partial character of the decomposition is indicated by the off-diagonal matrix elements.

The analytical task starts with blocks here called functional areas, representing satisfactory partial decomposition. In the study of analogy for firm strategy, Gavetti et al (2005) introduced an organization of **N**,**K** models that accommodates 'decomposition'. They identify feature groupings for firms as the "high-level policy (P) choices" that subsume sub-sets of "detailed action choices"(D). High-level policy choices represent 'functional areas' that collect a set of detailed characteristics into a module with the majority of **K** epistatic relations within the group, achieving partial decomposition. The structure developed by Gavetti et al. to model firm strategies begins by identifying P "high level" strategic choices, each of which includes D "detailed choices". Subgroups of Kaufman **N**s **(**features) are grouped into sets of features labeled with Ds. The sets of related Ds (our functional areas) are named by P values. To achieve a partial decomposition of cluster structures the empirical analysis will focus the four functional areas identified above, *knowledge structures*, *networks*, *talent*, and *infrastructure* (henceforth, italics refer to these functional areas). Detailed characteristics (Ds) for which interviews yielded sufficient data for analysis are for each of the functional areas:

- *Knowledge structure*

    Research institution relations

    Firm R&D strategy

    Global knowledge system relations

    Sources of local advantage with respect to knowledge

- *Networks*

  Character of networking linkages within the cluster, from formal to informal

  Key network anchors facilitating network development

  The extent of local networking in the value chain

- *Talent*

  Technical backgrounds of key employees

  Key recruiting focus of the firms

  Talent retention in the region

- *Infrastructure*

  Key finance sources for the development of the cluster

  Quality of life factors of the region

  Specialized professional services (e.g. accounting, intellectual property law)

This proposed partial description of the **N**,**K** (P,D) structure of our clusters may not be unique, and it is certainly not complete. However, it is sufficient to demonstrate how individual clusters may find different satisfactory solutions to the problem of gaining regional advantage. Do significantly different epistatic relationships exist between features in the different functional areas conceptualized as the modules in the decomposition of the **N,K** (D,P) matrix? Such significant differences in the linkages among the functional areas require the emergence of different overall architecture in the cluster model as it evolved. There are certainly limitations on the assignments made in interpretation of the interviews (triangulated over three researchers). However, it can safely be claimed that the presentation of this model shows the methodology of empirical **N**,**K** analysis as the tool to identify the complex linkages that reveal the path dependence characteristics that differentiate the three similar cases. Our partial decomposition model with identification of some ‘allele’ values derived from the empirical data appears in

Table 2. An important features shown is that 'allele' values in this empirical analysis are not limited to the binary choices used in simulation studies, nor are all features required to have the same value of **K**.

The goal of this exercise is to show that the three clusters have evolved into different regions of a fitness landscape (or are evolving on different fitness landscapes) using this partial **N**,**K** (P,D) model. The logic is that of proof by counter example. We do this if we can demonstrate important relationships that interconnect different functional areas and limit decomposition (off-diagonal elements). That is, do significantly different epistatic relationships exist between features in the different functional areas that were conceptualized as the modules in the decomposition of the **N,K** matrix? Such significant differences in the linkages among the functional areas require the emergence of different overall architecture in the cluster model as it evolved. Thus, either the three have explored different regions of a fitness landscape with the same overall set of features, or the 'genetic' structures differ enough to require different landscapes for their modeling.

Path dependent evolution

Despite the similarity of the relations to their global knowledge networks and their common geographic features, the three Western Canadian clusters have evolved on significantly distinct paths. Important epistatic relationships link different functional areas of the partial decomposition in significantly different ways. These relationships led to fundamental architectural differences. Comparison among the clusters reveals the existence of a number of such epistatic relationships, especially around the central aspect of *talent*. (Refer to Table 2 for the distribution of detailed characteristics under functional areas.) We can see how the analysis works taking the functional area (P) labeled *talent* as an initial example .

<u>Epistatic relationships in Calgary and Vancouver wireless telecommunications</u>. In both of these clusters, the fundamental factor in local success identified from all interviews reported was the *talent* pool or thick labour market. Key recruiting patterns are significant characteristics in the *talent* module that might have differentiated Calgary and Vancouver telecommunication cluster growth. In both locations, recruiting from other firms was most important, with a secondary emphasis on recruiting from post-secondary institutions. We thus see similar epistatic relationships within the functional area (module). However, this inter-firm recruiting is linked across modules to the nature of local *networks* (P) that are historically quite different. The Calgary *network* has characteristics of highly informality, growing out of

the veterans of the founding firm, NovAtel, who are widely distributed in five subsequent generations of wireless firms (Langford et al, 2003). This *network* is efficient but not readily accessed by newcomers. Vancouver had three distinctly different key initiating firms that assembled sections of the talent pool, complemented by a long history of an active technology industry association. The characteristics of *networking* are much more formal, strongly mediated through associations accessible to newcomers. As well, there is overlap of *talent* recruiting with the substantial and related Vancouver multimedia industry (Langford et al, 2005) such that *talent* is recruited into the telecommunication network locally but from outside wireless telecommunication. The "off-diagonal" relationship of recruiting *talent* with *network* module features, informal versus trade associations, is a significant differentiator, as is the role of an adjacent industry in one case but not the other.

The above differences in development from the linking the *talent* (P) module of the two clusters with detailed characteristics under the *networks* (P) module are complemented by differences linking *talent* (P) to the *infrastructure* (P) module*.* Within *infrastructure* characteristics of early cluster stage finance are local and government-related (a provincial utility) in Calgary. This contrasts with characteristics combining local private and non-local government (federal) stimulation in Vancouver, which relates across P values to the different characteristics of *network*s. The informality of *networks* in Calgary derives from the accumulation of *talent* in the single initial *anchor* firm with public sector support, NovaTel, from which personal relationships among members of firms throughout the cluster arose (Langford et al, 2003). In contrast, the early emergence of more formalized *networks* in Vancouver reflect linkages to the origins of the *talent* pool through the activities of at least three quite distinct anchor firms, of which two were entirely private (Langford and Wood, 2005).

Finally, *talent* retention in the two clusters relates in significantly different ways to the *infrastructure* module characteristic, quality of life. Interviewees praised Calgary as a clean, safe, low cost city in an attractive mountain setting for outdoor activities, with an entrepreneurial "can do" attitude and strong local services. Vancouver was characterized as a diverse, exciting, albeit expensive, urban center with a mild climate set in a beautiful conjunction of mountains and sea with a "laid back" attitude. In both cases, *talent* retention has the parallel characteristics of local and inter-firm mobile, but drivers linked to *infrastructure* are different. One interviewee stated: "*We didn't want to go to Toronto and we* *couldn't afford Vancouver, so we're in Calgary*". In contrast, a Vancouver interviewee reported: "*We were here and we didn't want to leave so we founded the firm.*" An executive who had come from a national firm and moved to a local firm to stay in Vancouver noted that the "laid back" attitude led to a work style inconsistent with other elements of the national firm. A similar inconsistency arise with Calagry.

A special off-diagonal epistatic relationship with GPS. *Talent* was placed centrally in GPS as was the in two wireless examples. However, the GPS cluster exhibited a unique relation between *talent* recruiting and the *knowledge structure* role of universities that was absent from wireless telecommunications. The Geomatics Engineering program at the University of Calgary, stimulated by its own recruiting from an early local anchor firm, worked through international professional associations to establish Calgary as a recognized center for GPS. The success of this initiative led to an important *talent* recruitment path for researchers into the university from an international pool. Interviewees estimated that approximately 50% of this *talent* was retained in the local industry. Thus, a *knowledge structure* focus by the university department influences a *talent* recruiting focus on research training and an entry path quite different from the wireless clusters' interest in recruiting from post-secondary institutions. Thus, this unique relationship with the university is one of the features distinguishing Calgary GPS structure from either Calgary of Vancouver wireless telecommunication.

The value of organizing the data into an evolutionary matrix model is in the way that attention is drawn to the details of the complex relationships associated with the development path of each case. The contrasts and similarities stand out.

DISCUSSION

Following the example of Silicon Valley, many have recognized technological clusters as a key driver of innovative behavior, industrial competitiveness and economic growth. However, critics have argued that cluster analyses have been conceptually and methodologically weak or overly simplistic attempts at identifying key success factors that can be copied elsewhere. Drawing on Kauffman's N,K theory (with P,D organization), we have identified some diagnostic aspects of the evolutionary structure of industrial clusters in their regional environment. We show how variation in interactions among elements of different functional areas plays a crucial role in the development of a cluster. The three clusters presented here evolved (or are evolving) into different regions of fitness landscapes, through the interconnected relationships among functional areas that limit any decomposition of the design problem. This approach helps explain why actionable checklists, easily interpreted recipes and 'success ingredient models' (Martin and Sunley, 2003) applied to an inherently rugged landscape are likely to lead to 'Silicon nowhere's' (Florida) and 'policy lemons' (Cook, 2006). Rather than a recipe for success, simplistic imitations of successful regions that fail to recognize the inherently complex (i.e. rugged) landscape of cluster formation are likely to be at best a shot in the dark, and at worst a recipe for disaster. The lessons of Rivkin's (2000) model of failures of firm imitation apply to clusters as well. That any characteristic of one cluster will enjoy exactly the same epistatic relations in another in not highly probable.

We do not imply that the analysis given above allows tracing of the full evolutionary pattern of the three clusters. The empirical information, both qualitative and quantitative, is insufficient to approach a full **N**,**K** (or P,D) matrix for such a complex phenomenon. We also recognize limitations in the empirical data. They do not go beyond what the interviewees as a group were able to articulate and the researchers were able to interpret. Even an **N,K** model abstracts from the full complexity of the systems. Indeed, a full **N,K** matrix may be unattainable in principle. What is sufficient to accomplish our objective is to show that the three regional industry concentrations that analysts have described as clusters evolve to produce distinct emergent structures. The success of the regional industries establishes that each of these distinct structures has produced advantages.

The explicit use of the **N**,**K** model at the empirical rather than formal level, although necessarily incomplete, can illuminate significant architectural differences and provide richer clues to the nature of regional advantages than that achieved by a static catalogue of quantifiable specific characteristics (Gibson and Padmore, 1996; Porter 1990) and complement the extensive anecdotal evidence from business history cases. Recent applications of N,K theory to innovative behavior that illuminate fundamental structural issues have been based on formal modeling or simulations. We suggest that empirical data can be a useful means by which certain aspects, such as functional areas (P), can be identified and analyzed. Thus, we build on the recent studies of Rivkin (2000), Gavetti et al, (2005) Franken, (2001) and Choi et al (2001) by illustrating empirical utility for complexity theory. Additionally, we also contribute to complexity theory concerned with innovation dynamics by taking the analysis to the next level of complexity, the cluster, with relaxation of arbitrary rules for epistatic relations that digital models require.

Analogy in cluster policy formation

The variations in "satisfactory" (Simon, 1968) structures that can arise in similar fundamental circumstances counsel against implementing policies based on benchmarking a particular case's performance with respect to a standard feature list or a single model. According to DiMaggio and Powell (1983), such approaches may be alluring, but suffer from the risks in imitation and isomorphism that may not encourage satisfactory solutions. Flexible use of analogy can provide an alternative. Policy makers draw on analogy to their own experiences or to other cases with which they are familiar. Indeed, in our experience, cluster policy practitioners commonly apply analogical reasoning, although they often refer to it as 'accumulated knowledge' or 'gut feel'. Thus, it is important to explore the status of analogies in the context of a complexity analysis. The Gavetti et al (2005) **N**,**K** (P,D) simulation model explored analogy as a strategic tool for firms. It begins with a partial decomposition into modules identified as high-level policies that correspond to our functional areas and the formal properties of the simulation correspond to our cluster model. Thus, most of the implications of their simulation apply to clusters as well.

The first guideline for exploiting analogy is to achieve a good partial decomposition into modules (high level features) for the target cluster for policy intervention. In the case of a cluster based on global science, modules similar to the functional areas above are likely to be useful, but ultimately context-specific analysis is required to identify appropriate functional areas for other industrial clusters, and is indeed a starting point for policy development. However, careful consideration of the modularization is essential – in spite of numerous attempts in cluster studies, modularization cannot be pre-defined. The identification of key success factors applied from a different jurisdiction is likely to result in an unsatisfactory location in a fitness landscape. We suggest judicious use of analogies at the level of the functional areas. In searching analogous properties, attention can be given to a wide range of sources for the identification of analogous features. Breadth of experience or breadth of known cases often appears to be more valuable than depth of knowledge of the analogs, although both are useful. This points to initial analogy drawn at the level of the functional areas and a subsequent experimental process of adaptive incremental adjustments to achieve the local high point of the fitness landscape. In addition, restricting attention during incremental adjustment to strict use of the analogy and rejecting search over detailed features that link across functional area boundaries can be unprofitable, especially when the decision problem is not easily decomposed and numerous epistatic relations across functional areas are important. Clearly, a large measure of detailed search is involved in achieving desirable goals.

Future Directions

Especially since the success of Silicon Valley, the vast majority of the cluster discourse has been preoccupied either with the identification of key success characteristics or with the deficiencies of the models, conceptual treatment and definitional constructs in cluster studies. While the cluster discourse has been valuable for directing attention to the potential sources of advantage derived from innovation dynamics and geographical agglomeration, it appears that current pre-occupations have led to stagnation. We suggest that a reason for this stagnation is that the discourse is asking questions in the wrong direction – the extensive exercises in identification of key success factors, while useful for the specific cases, has been used to define how we understand a successful cluster, and consequently drive what policy-makers believe they should recreate in their own jurisdictions. Our complexity analysis confirms that clusters are idiosyncratic and path dependent, and they commonly evolve toward their own unique high points of fitness landscapes. The role of policy and research is to explore the emergence of unique regional characteristics, understand their dynamic interactions with other characteristics, and encourage adaptive experimentation toward exploitation of unique strengths.

REFERENCES

Aldrich, H. & Fiol, C. 1994. Fools Rush In? The institutional context of industry creation. ***Academy of Management Review*** 19: 645-670.

Arthur, W. 1990. Positive feedbacks in the economy. ***Scientific American*** February, 92–9.

Audretsch D. 1998. Agglomeration and the location of innovative activity, ***Oxford Review of Economic Policy*** 14(2): 18-29.

Axelrod, R., Cohen, M. 1999. ***Harnessing Complexity: Organizational Implications of a Scientific Frontier.*** New York, The Free Press.

Choi, T., Dooley, K. & Rungtusanatham, M. 2001. Supply networks and complex adaptive systems: control versus emergence. ***Journal of Operations Management,*** 19: 351–366.

Christensen, C. 1997. ***The Innovators Dilemma***. Cambridge, Mass: Harvard Business School Press.

Cooke, P. & Leydesdorff, L. 2004. Regional development in the knowledge-based economy: The construction of advantage, in Cooke, P. & Leydesdorff, L. (eds.) The Knowledge-Based Economy and Regional Development. Forthcoming in Special issue of the ***Journal of Technology Transfer.***

Cooke, P. 2006, Regional capabilities and open innovation: regional innovation systems and clusters in the asymmetric knowledge economy. In Breschi, S, Malerba, F. Clusters, networks, and innovation, Oxford University Press, Oxford, 2006. Chapter 4.

Cyert R. & March J. 1963. ***A Behavioral Theory of the Firm***. Prentice-Hall: Englewood Cliffs, NJ

De la Mothe, J. & Mallory, G. 2003. Industry-Government Relations in a Knowledge-Based Economy: the Role of Constructed Advantage, PRIME Discussion Paper 02-03, University of Ottawa: Program of Research in Innovation Management & Economy.

DiMaggio, P. & Powell, W. 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. ***American Sociological Review***, 48: 147-160.

Eisenhardt, K. 1989. Building theories from case study research. ***Academy of Management Review,*** 14(4): 532-550.

European Commisssion, IRE. 2005. Mutual Learning Platform: Workshop on Regional Profiles and Growth Poles. Brussels, December, 2005. http://www.innovating-regions.org/download/MLP. Regional profiles and Growth Poles, 9 December 2005_report.pdf. Accessed 23 May 2006.

Fabiani, S. & Pellegrini, G. 1998. Un'analisi quantitative della imprese nei distretti industriali italiani: redditvità, produttività e costo del lavoro, L'Industria. ***Rivista di economia e politica industriale,*** 19, 811–831.

Fligstein. N. 1991. The structural transformation of American industry: An institutional account of the causes of diversification in the largest firms, 1919-1979, In Powell, W. & DiMaggio, P (eds,), ***The New Institutionalism in Organizational Analysis***: 311-336. Chicago: University of Chicago Press.

Florida, R. 2002. The rise of the creative class, ***Washington Monthly***, 34(5): 15-26.

Foray, D. & Freeman, C. 1993. ***Technology and the Wealth of Nations: The Dynamics of Constructed Advantage***. London: Pinter

Freeman, C & Soete, L. 1997. ***The Economics of Industrial Innovation***, MIT, Cambridge MA.

Frenken, K. 2001. Understanding Product Innovation using Complex Systems Theory, PhD thesis, University of Amsterdam.

Frenken, K. 2006. Technological innovation and complexity theory, ***Economics of Innovation and New Technology***, 15(2): 137.

Furman J., Porter M. & Stern S. 2002. The determinants of national innovative capacity. ***Research Policy*** 31(6): 899–933

Garnsey E. 1998. The genesis of the high technology milieu: A study in complexity, ***International Journal of Urban and Regional Research***, 22(3): 361-377.

Gavetti, G, Levinthal, D. & Rivkin, J. 2005. Strategy making in novel and complex worlds: The power of analogy. *Strategic Management Journal* 26(8): 691-712.

Gertler, M. 1995. Being there: Proximity, organization, and culture in the development and adoption of advanced manufacturing technologies. ***Economic Geography*** 70(4):1-26.

Gertler, M., Florida, R., Gates, G., & Vinodrai, T. 2002. Competing on creativity: Placing Ontario's cities in North American context. Report prepared for the Ontario Ministry of Enterprise, Opportunity and Innovation, and the Institute for Competitiveness and Prosperity, Toronto, December. Available at: www.utoronto.ca/progris/recentpub.htm

Hakanson, L. 2005. Epistemic communities and cluster dynamics: On the role of knowledge in industrial districts, ***Industry and Innovation***, 12(4): 433-463

Hoffman, A. 1999. Institutional evolution and change: Environmentalism and the U.S. chemical industry. ***Academy of Management Journal***, 42: 351-371.

Jensen, M. & Meckling, W. 1976. Theory of the firm: Managerial behavior, agency costs, and ownership structure ***Journal of Financial Economics***, 3: 305-360.

Kauffman, S. 1993. ***Origins of Order: Self-Organization and Selection in Evolution***. Oxford University Press, Oxford.

Kauffman, S. & Levin, S. 1987. Towards a general theory of adaptive walks on rugged landscapes. ***Journal of Theoretical Biology***, 128: 11.

Kauffman, S., Lobo, J. & Macready, W. 2000. Optimal search on a technology landscape, ***Journal of Economic Behavior & Organization***, 43: 141–166

KPMG, 2005. 2005 Alberta wirelesss and telecom industry survey. KPMG LLP, Canada. Available at www.kpmg.ca

Krugman, P. 1991. ***Geography and Trade***. MIT Press, Cambridge, MA.

Langford, C., Hall, J., Josty, P., Matos, S., & Jacobson. A. 2006. Outcomes of University Research in Canada: Innovation Policy and Indicators of Triple Helix Relationships, ***Research Policy***. 35(10): 1586–1598.

Langford, C. Wood, J. & Ross, T. 2003. The origin and structure of the Calgary wireless cluster, in: Wolfe, D. (ed), ***Clusters Old and New***, McGill-Queens, Press, Montreal, Chap. 6.

Langford, C. Wood, J. & Jacobson, A. 2005. The evolution and structure of the Vancouver wireless cluster, in: Wolfe, D.A. and Lucas, M. (Eds). ***Global Networks and Local Linkages,*** McGill-Queen's Press, Montreal, Chap. 8.

Laughlin, R.B. 2005. A different universe, re-inventing physics from the bottom down. Basic Books, New York, 2005.

Lawrence, T, Winn, M & Jennings, P. 2001. The temporal dynamics of Institutionalization, ***Academy of Management Review***, 26(4): 624-644.

Leblebici. H., Salancik, G. Copay. A., & King, T. 1991. Institutional change and the transformation of inter-organizational fields: An organizational history of the U.S. radio broadcasting industry. ***Administrative Science Quarterly***, 36: 333-363.

Levinthal, D. & Warglien, M. 1999. Landscape design: designing for local action in complex worlds. ***Organization Science*** 10(3): 342-358.

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

Malmberg, A & Power, D. 2005. (How) do (firms in) clusters create knowledge? ***Industry and Innovation*** 12(4): 409-431.

Marshall, A. 1947. ***Principles of economics****.* Cambridge University Press.

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

Matos, S. and Hall, J., 2007. Integrating sustainable development in the supply chain: the case of life cycle assessment in oil and gas and agricultural biotechnology. ***Journal of Operations Management***, 25 (6), 1083–1102.

McKelvey, W. 1999. Avoiding complexity catastrophe in coevolutionary pockets: Strategies for rugged landscapes, ***Organization Science***, 10, 1999, 294–321.

Melecki, J. 1985. Industrial location and corporate organization in high-tech industries. ***Economic Geography***, 61: 345-369.

Meyer. J. & Rowan, B. 1977. Institutionalized organizations: Formal structure as myth and ceremony. ***American Journal of Sociology***, 83: 340-363.

Nelson, R. & Winter, S. 1977. In search of useful theory of innovation. ***Research Policy*** 6: 36–76.

Nelson R. & Winter S. 1982. ***An Evolutionary Theory of Economic Change***. Belknap: Cambridge, MA.

Padmore, T. & Gibson, H. 1998. Modelling systems of innovation II. A framework for industrial cluster analysis in regions. ***Research Policy*** 26: 625-641.

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

Penrose, E. 1995. ***The Theory of the Growth of the Firm*** (3rd ed.). Oxford: Oxford Univ. Press.

Lucas, M. Global Networks and local linkages, McGill-Queen's Press, Montreal and Kingston, 2005. Chapter 3.

Porter, M. & Stern S. 2001. Innovation: Location matters. ***MIT Sloan Management Review***, 42(4): 28-36

Porter, M. 1990. ***The Competitive Advantage of Nations***. Free Press, New York.

Porter, M. 1998. Clusters and the new economics of competition. ***Harvard Business Review*** 76: 77–90.

Pouder, R. & St John, C. 1996. Hot spots and blind spots: Geographical clusters of firms and innovation. ***Academy of Management Review***; 21(4): 1192-1225.

PwC 2005. *2005 BC Wireless Industry Survey*, PricewaterhouseCoopers LLP, Vancouver.

Richardson, G. 1972. The organisation of industry. ***The Economic Journal*** 82: 883–896.

Rivkin J. 2000. Imitation of complex strategies. ***Management Science*** 46: 824–844.

Rogers, E. 1994. ***Diffusion of Innovations***, 4th ed., Free Press, New York.

Rugman A. & Verbeke A. 1993. Foreign subsidiaries and multinational strategic management: an extension and correction of Porter's single diamond framework. ***Management International Review*** 33(2):71-84

Rugman A. & Verbeke A. 2004. A perspective on regional and global strategies of multinational enterprises. ***Journal of International Business Studies***, 35(1): 3-18.

Ryan, C. & Phillips, P. 2003. Intellectual property management in clusters: A framework for analysis" in D. Wolfe (ed) ***Clusters Old and New -- The Transition to a Knowledge Economy in Canada's Regions***, Kingston & Montreal: McGill-Queen's University Press for the School of Policy Studies, pp 95-120.

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

Schumpeter, J. 1942. ***Capitalism, Socialism, and Democracy***. New York: Harper and Brothers.

Scott, A. 1989. ***New Industrial Spaces: Flexible Production Organization and Regional Development in North America and Western Europe***. London, Pion.

Silvestre, B. and Dalcol, P., 2009. Geographical proximity and innovation: evidences from the Campos Basin oil & gas industrial agglomeration – Brazil. ***Technovation***, 29 (8), 546–561.

Simon, H. 1969. ***The Sciences of the Artificial***. Cambridge, Mass, MIT Press.

Steinle, C. & Schiele, H. 2002. When do industries cluster? A proposal on how to assess an industry's propensity to concentrate at a single region or nation. ***Research Policy,*** 31: 849–858.

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

Storper, M. & Venables, A. 2003. Buzz: face-to-face contact and the urban economy. ***Journal of economic geography***. 4: 351-370

Storper, M. 1995. The resurgence of regional economies, ten years later: The region as a nexus of untraded interdependencies. ***European Urban and Regional Studies*** 2(3): 191-221.

Tolbert, P. & Zucker, L. 1983. Institutional sources of change in the formal structure of organizations: The diffusion of civil service reform, 1880-1935. ***Administrative Science Quarterly***. 28: 22-39.

Tushman, M. & Anderson, P. 1986. Technological discontinuities and organizational environments. ***Administrative Science Quarterly,*** 31: 439-465.

Van de Ven, A. & Poole, M. 1995. Explaining development and change in organizations. ***Academy of Management Review***, 20(3): 510-540

Van de Ven, A. 1986. Central problems in the management of innovation, ***Management Science.*** 32(5): 590-607.

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

Wolfe, D & Gertler, M. 2003.***,*** *Lessons from the ISRN Study of Cluster Development*, **Clusters Old and *New,*** McGill Queens Press, Montreal & Kingston, Ch 1.

Wolter, K. 2005. Divide and Conquer? Decentralisation, Co-ordination and Cluster Survival, Danish Research Unit for Industrial Dynamics (DRUID) Working Paper No. 05-12.

Author bios:

Cooper H Langford, AB (Harvard), Ph.D.(Northwestern), FRSC is Faculty Professor in Communication and Culture at the University of Calgary. He is a former Vice President for Research at Calgary and a former director of Physical and Mathematical Sciences at the Natural Sciences and Engineering Research Council of Canada. He is a Fellow and a Board member of the Centre for Inovation Studies (THECIS). He publishes on innovation and knowledge flow between universities and other sectors. Contact: chlangfo@ucalgary.ca, 2500 University Dr NW, Calagry, AB Canada T2N 1N4. Tel. 402 220 3228.

Jeremy K Hall, Ph.D. D.Phil. (Sussex), MBA (Dalhousie), B.Sc. (Dalhousie) is Asociate Professor in the Beedie School of Business at Simon Fraser University. Editor in chief of the journal Engineering and Technology Management. His research focuses on sustainable development innovation, stakeholder ambiguity, social impacts of innovation, entrepreneurial learning for social inclusion, sustainable supply chains and Brazilian industrial policy. Dr Hall currently holds a SSHRC grant exploring the impact of Brazilian poverty reduction programs on entrepreneurial dynamics, whether they lead to productive, unproductive or destructive outcomes. He is also the lead investigator for two GE3LS (Genomics, Economy, Economics, Ethics, Law and Society) Genome Canada grants investigating the commercialization of biotechnology in the forestry sector. His work is extensively published in leading journals. Contact: jkh5@sfu.ca. Beedie School of Business, Simon Fraser University, 8888 University Dr, Burnaby, BC, Canada, V5A 1S6. Tel. 778 782 5891.

Table 1: *Samples of studies using the biological metaphor related to products, firms,*

	<u>*Relatively low*</u>		**Dimensions of Complexity**	<u>*Relatively High*</u>	
Biological Analogy	**Frenken, 2001**	**Rivkin, 2000**	**Choi et al, 2001**	**This paper**	
Species	Product range (e.g. Boeing 777, Airbus)	Industry	Supply Networks	***Innovation system*** (e.g. int. science-base, industry players, infrastructure, institutions, etc)	
Organism **(Unit of analysis)**	Product (e.g. aircraft)	Firm	Focal (purchasing) firm	***Cluster*:** (e.g. wireless firms, local knowledge support and infrastructure)	
Genes (features)	Selected component (e.g. wing)	Selected strategy	Suppliers	***Selected gov't policies & managerial strategies*** (e.g. initiating stimuli; recruiting practices)	
Alleles (options)	Component variations (e.g. swept versus straight)	Strategic options	Supplier strategy (e.g. control schemes, # of suppliers (reduced transaction costs vs. supply risk etc.)	***Regional variations and strategic options:*** ***Regional Variations*** (e.g. gov.'t action, local demand, investment characteristics; local grads, experienced externals)	***Managerial Options*** (e.g. location choices, collaborative RD, recruiting practices)

Table2: Functional Areas - partial decomposition and identification of 'allele' values derived from the empirical data.

Functional Areas

	Knowledge structure				Networks			Talent			Infrastructure				
	Key research institutions	R&D strategy	Knowledge system relations	Knowledge source advantage	Intra-cluster Linkages	Anchors	Value chain networks	Key technical back-ground	Key Recruiting focus	Retention	Key finance	Quality of Life			Services
												Scale	***Setting***	***Cost***	
Value 1	Universities	Formal R&D Labs	Globally Open	Codified knowledge Producer	Informal	Gov't stimulated	Users	Balanced experience	Other firm	Locally mobile	Local, gov't related	Urban	Cosmo-politain	High	Local
Value 2	Firm R&D	close link to shop floor	Local and specific	Tacit knowledge Producer	Trade associations	Private	Suppliers	Research back-ground	Post-secondary	Inter-nationally mobile	Local private	Small	Natural	Low	Non-local
Value 3	Public Labs			Balanced mix	Institutionally-based	University	Comp et-itors		Research training	Non-mobile	Lon-local private		Low stress		
Value 4											Non-local gov't related				